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1952

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ABBREVIATIONS AND SYMBOLS

Å.	Ångstrom unit(s) = 1×10^{-10} m.
A.C.	air-cooled; alternating current
A.H.	air-hardened
amp.	ampère(s)
amp.hr.	ampère-hour(s)
approx.	approximately
at.-%	atomic per cent
at.wt.	atomic weight
atm.	atmosphere(s) (pressure)
A.W.G.	American wire-gauge
° Bé.	Baumé (degree)
b.h.p.	brake horse-power
B. & S.	Brown and Sharpe (gauge)
B.o.T.	Board of Trade
b.p.	boiling point
B.T.U.	Board of Trade unit(s)
B.Th.U.	British thermal unit(s)
B.W.G.	Birmingham wire-gauge
° C.	centigrade; Celsius (degree)
cal.	calorie(s)
c.c.	cubic centimetre(s)
c.d.	current density
c.g.s.	centimetre-gramme-second unit(s)
cm.	centimetre(s)
coeff.	coefficient(s)
conc.	concentrated
const.	constant(s)
cu.	cubic
cwt.	hundredweight(s)
D.C.	direct current
dia.	diameter
dil.	dilute
dm.	decimetre(s)
e.m.f.	electromotive force
e.v.	electron volt(s)
° F.	Fahrenheit (degree)
ft.	foot, feet
ft.lb.	foot-pound(s)
g.	gramme(s)
gal.	gallon(s)
H.F.	high-frequency
h.p.	horse-power
h.p.hr.	horse-power-hour(s)
hr.	hour(s)
in.	inch(es)
in.lb.	inch-pound(s)
I.S.W.G.	Imperial standard wire-gauge
° K.	absolute temperature (Kelvin scale)
kg.	kilogramme(s)
kg.cal.	kilogramme-calorie(s)
kg.m.	kilogramme-metre(s)
km.	kilometre(s)
kV.	kilovolt(s)
kVA.	kilovolt-ampère(s)
kW.	kilowatt(s)
kWh.	kilowatt-hour(s)
kX.	crystal Ångstrom(s) = 1000 Siegbahn X-units

l.	litre(s)
lb.	pound(s)
L.F.	low-frequency
M	molar (solution)
m.	metre(s)
m.amp.	milliampère(s)
max.	maximum
mg.	milligramme(s)
min.	minimum; minute(s)
ml.	millilitre(s)
mm.	millimetre(s)
m.m.f.	magnetomotive force
m.p.	melting point
mV.	millivolt(s)
mμ	millimicron = 1×10^{-9} m. = 10 Å.
N	normal (solution)
N.T.P.	normal temperature and pressure
O.H.	open-hearth; oil-hardened
O.Q.	oil-quenched
oz.	ounce(s)
p.d.	potential difference
*p*H	hydrogen-ion concentration
p.p.m.	parts per million
r.p.m.	revolutions per minute
sec.	second(s)
sp.gr.	specific gravity
sq.	square
S.W.G.	standard wire-gauge
T.	tempered
temp.	temperature
V.	volt(s)
VA.	volt-ampère(s)
W.	watt(s)
Wh.	watt-hour(s)
W.G.	water-gauge
W.Q.	water-quenched
wt.	weight
wt.-%	weight per cent
yd.	yard(s)
μ	micron(s) = 1×10^{-6} m.
μg.	microgramme(s) = 1×10^{-6} g.
μμ	1 millionth micron = 1×10^{-12} m. = 0·01 Å.
Ω	ohm(s)
°	degree (arc or temperature)
′	minute of arc; foot (feet)
″	second of arc; inch(es)
$<$	less than
$>$	greater than
$\not<$	not less than
$\not>$	not greater than
$\leqslant$	equal to or less than
$\geqslant$	equal to or greater than
$\neq$	not equal to
$\equiv$	identically equal to
$\simeq$	approximately equal to
$\propto$	proportional to

Unless otherwise stated above, the symbols given in the following British Standards are used in the *Journal:* Chemical, Thermodynamical, and Physico-chemical quantities: B.S. 813; Engineering units: B.S. 560.

CAPTAIN H. LEIGHTON DAVIES, C.B.E., J.P.

CAPTAIN HECTOR LEIGHTON DAVIES, eldest son of the late Sir John C. Davies, Managing Director of Baldwins, Ltd., was born at Sebastapool, Panteg, Mon., in 1894. He was educated at Malvern College, and afterwards entered the Landore works of Baldwins, Ltd.

In September, 1914, he joined the Swansea Battalion, the Welch Regiment, and was mentioned in Despatches. He was invalided out in 1915, and was then seconded to the Ministry of Munitions. Two years later he returned to Baldwins, Ltd., at their Gowerton Works. In 1921 he was appointed General Manager of the steel and tinplate interests of Baldwins, Ltd., in South Wales, and was elected a Director.

At the outbreak of the last war Captain Davies accepted the position of Director of Scrap and Tinplate, Iron and Steel Control, Ministry of Supply. In 1945, on the amalgamation of Baldwins, Ltd., and Richard Thomas and Co., Ltd., he became a Director of Baldwins (Holdings), Ltd., and a General Manager of Richard Thomas and Baldwins, Ltd., in charge of their steel and tinplate interests in West Wales. In July, 1947, on the formation of The Steel Company of Wales, Ltd., Captain Davies was elected to the Board, and in September, 1947, was appointed Assistant Managing Director.

During the last war Captain Davies was a Member of the Wales Regional Board of the Ministry of Aircraft Production, and from 1940 to 1945 he was Area Controller (Wales) of the Emergency Services Organisation of the Iron and Steel Control.

Captain Davies has always played a prominent part in encouraging metallurgical research and its application to the steel and tinplate industries of South Wales. He became a founder member of the Swansea and District Metallurgical Society in 1919, and in 1945 he was elected President. In 1946 he became a Member of Council of the British Iron and Steel Research Association, and is Chairman of its Coatings Committee. He is a Member of the Council and Executive of the British Iron and Steel Federation, and has been a member of the Central Council of Wages since 1928; he has acted as Chairman of the Federation's Scrap Committee since 1937. He is Vice-Chairman of the Tinplate Conference and of the Welsh Plate and Sheet Manufacturers' Association, and Chairman of the Welsh Plate and Sheet Trades Joint Industrial Council. He was a member of the International Tinplate Association from 1939 until its dissolution after the war; in 1951 he was also Chairman of the International Scrap Association.

Captain Davies has a long record of service on public bodies. He became a Justice of the Peace in 1928, and among his many interests at the moment are: Chairman of the South Wales Industrial Savings Committee ; Chairman of Swansea and District Employment Committee; Member of Council of the University College of Swansea; Member of the Welsh Board for Industry; and Member of Council, Industrial Welfare Society, Inc. He has also served for over 21 years on the Local District Council and is a Past-President of the Swansea Chamber of Commerce. He was awarded the C.B.E. in 1941.

In 1918 Captain Davies became a Life Member of The Iron and Steel Institute. He was elected a Vice-President in 1944 and President in 1952.

Captain H. Leighton Davies, C.B.E., J.P.
President, 1952-1953

PROCEEDINGS OF THE INSTITUTE

REPORTS OF COUNCIL - OFFICIAL NOTICES

REPORT OF COUNCIL FOR 1951

H.M. KING GEORGE VI

It is with the deepest regret that the President and Council record the death of His Majesty King George VI. The King became Patron of the Institute in 1936.

At a meeting of the Council held on 5th March, 1952, it was resolved to send the following address to Her Majesty Queen Elizabeth II:

To The Queen's Most Excellent Majesty

May it please Your Majesty,

We, Your Majesty's loyal, attached, and dutiful servants, the President and Council of The Iron and Steel Institute today assembled at a meeting of the Council, present our humble duty to Your Majesty and desire to be permitted to offer to Your Majesty, to Her Majesty the Queen Mother, Her Majesty Queen Mary, and the other members of the Royal Family, their profound sympathy at the loss which has befallen Your Majesty and the whole Commonwealth through the death of your father, our beloved Sovereign Lord, KING GEORGE.

The members of The Iron and Steel Institute share the deep and heartfelt sorrow of all Your Majesty's subjects at the loss of a Sovereign who throughout his reign was unremitting in his devotion to the welfare of his peoples. His interest in the prosperity and well-being of the industries with which the members of this Institute are associated, and in the development of the science of metallurgy, was a source of great encouragement to the members. They valued highly the honour accorded to them when he graciously agreed in 1936 to become the Patron of this Institute.

The President and Council also desire to offer their dutiful and humble congratulations to Your Majesty on your Accession to the Throne. They pray that the blessings of health, long life, prosperity, and happiness may be vouchsafed to Your Majesty, and to your august and beloved husband, Prince Philip, Duke of Edinburgh.

GIVEN under the Seal of The Iron and Steel Institute this fifth day of March in the Year of our Lord One Thousand Nine Hundred and Fifty-two.

(*Signed*) RICHARD MATHER, *President*

(*Signed*) KENNETH HEADLAM-MORLEY, *Secretary*

A reply to the above Address was received as this issue of the Journal was going to press. It is printed on p. 8.

Annual Report

THE Council submit this, their Annual Report and Statement of Accounts for the year 1951, to Members for their approval at the Eighty-third Annual General Meeting of The Iron and Steel Institute.

The work of the Institute was continued successfully throughout the period covered by the Report.

The Annual and Autumn General Meetings were held in London in May and November, and a successful Special Meeting was organized in Austria during September. Other meetings included a Symposium on High-Temperature Steels and Alloys for Gas Turbines and a Symposium on the Corrosion of Buried Metals, which were held in London on 21st and 22nd February and 12th December, respectively.

The Engineers Group organized a number of interesting meetings which were well attended.

Income again exceeded expenditure for the year, although the credit balance was not so large as at the end of the previous year.

ROLL OF THE INSTITUTE

The total membership at 31st December, 1951, was 4776, compared with 4882 at 31st December, 1950.

The further drop in total membership is again due to a reduction in the number of Associate Members. The total number of them declined from 702 on 31st December, 1950 (857 in 1949), to 552 at 31st December, 1951. The total of Ordinary and Life Members increased and again is higher than on any previous occasion. The figures are (at 31st December) : for 1949, 4025 ; for 1950, 4149 ; and for 1951, 4221.

During the year, 221 Ordinary and 70 Associate Members were newly elected or reinstated. The deaths of 43 were reported ; 239 resigned, 101 were struck off the Roll of Members, and 12 elections lapsed for non-payment of the subscriptions due.

An analysis of the membership at 31st December, 1951, is given in Table I, whilst the membership trend since the Institute was founded is shown in Fig. 1.

OBITUARY

The Council regret to announce the deaths of 43 Members ; of these, the following 24 occurred during 1951 :

BEST, O. F. (Cardiff)	17th July
BRUNTON, J. D. (Musselburgh) ..	5th July
CAULFIELD, K. W. (Hayes, Middx.)	25th January
CLEMENTS, F. (Eastbourne) ..	19th September
COADE, S. G. (Redcar)	19th January
CROOKE, Arthur (Scunthorpe) ..	30th April
DAVIES, Thomas F. (Newport) ..	Date unknown
ELLIS, JOHN D. (Chichester) ..	31st August
FORNANDER, S. G. E. (Stockholm, Sweden)	27th January
FRANCIS, Herbert (Sheffield) ..	5th January
GLENN, G. (Sheffield)	1st March
HOBSON, H. J. (Sheffield)	26th June
KIPGEN, A. (Luxembourg) ..	11th August
LUND, H. (Harborough)	22nd February
MCFARLAND, A.J. (Wheeling, U.S.A.)	26th February
MILLS, T. F. (Wirral)	20th February
ROSS, D. M. (Sydney, Australia) ..	9th January
ROYCE, H. M. W. (Manchester) ..	8th October
TURNER, *Prof.* T. (Leatherhead) ..	31st January
WALKER, Frank (Liverpool) ..	21st September
WASS, O. H. (Sheffield)	20th April
WEBB, L. W. T. (Swansea) ..	25th February
WILKINSON, T. S. (Leeds)	24th October
YOUNG, J. R. (Newcastle, Australia)	5th January

Table I—MEMBERSHIP OF THE IRON AND STEEL INSTITUTE AT 31ST DECEMBER, 1951, AND COMPARISON WITH 1950

	Membership at 31st December, 1951												1950		
	Ordinary Membership		Joint Membership with—						Totals		Total Membership		Grand Totals	Total Membership		Grand Totals
			Institute of Metals		Institution of Metallurgists		Both Institute and Institution									
	Home	Over-seas	Home	Over-seas	Home	Over-seas	Home	Over-seas	Home	Over-seas	Home	Over-seas		Home	Over-seas	
Patron	1	...	...	...	...	...	...	...	...	...	1	...	1	1	...	1
Members:																
Hon. Vice-Presidents	11	6	1	...	...	...	1	...	2	...	13	6	19	12	5	17
Hon. Members	2	4	1	...	...	...	...	...	1	...	3	4	7	4	3	7
Non-Paying Members	5	1	...	...	...	...	...	...	...	...	5	1	6	5	1	6
Life Members	59	22	3	4	7	...	4	...	14	4	73	26	99	73	26	99
Ordinary Members	1700	742	426	330	433	41	399	51	1258	422	2958	1164	4122	2929	1121	4050
Total (Members)	1778	775	431	334	440	41	404	51	1274	426	3053	1201	4254	3024	1156	4180
Associate Members	165	27	236	27	28	3	35	1	299	31	464	58	522	622	80	702
Total (both classes)	1943	802	667	361	468	44	439	52	1573	457	3517	1259	4776	3646	1236	4882

CHANGES ON THE COUNCIL

President-Elect

At the Autumn General Meeting it was announced that the Council had unanimously decided to nominate Capt. H. Leighton Davies, C.B.E., to become President at the Annual General Meeting in 1952.

Other Changes

During 1951, Mr. I. F. L. Elliot (Member of Council) and Mr. N. H. Rollason (Member of Council) were nominated to be Vice-Presidents, and Professor J. H. Andrew (Vice-President), Sir Arthur Matthews, O.B.E. (Member of Council), and Dr. J. Oberegger were elected Honorary Vice-Presidents. Mr. H. Boot (Consett Iron Co., Ltd.), Mr. S. Thomson (Colvilles, Ltd.), and Mr. E. T. Judge (Dorman Long and Co., Ltd.) accepted invitations to become Members of Council.

The following agreed to serve as Honorary Members of Council during their presidencies of the Societies named, in succession to their predecessors: Professor A. J. Murphy, M.Sc. (Institute of Metals, following Mr. H. S. Tasker), Mr. N. C. Lake (Cleveland Institution of Engineers, following Mr. G. B. Thomas), Mr. F. E. Probyn (Ebbw Vale Metallurgical Society, following Mr. J. H. Steele), Mr. F. K. Neath (Leeds Metallurgical Society, following Mr. G. W. Green), Mr. V. L. Farthing (Liverpool Metallurgical Society, following Mr. H. Edwards), Mr. A. B. Ashton, M.Sc. (Manchester Metallurgical Society, following Mr. E. J. Heeley), Mr. E. T. Gill, B.Sc. (Sheffield Metallurgical Association, following Dr. J. White), Mr. L. A. S. Perrett (Swansea and District Metallurgical Society, following Captain H. J. Thomas), and Professor R. Hay, Ph.D., B.Sc. (West of Scotland Iron and Steel Institute, following Mr. W. Barr).

The following continued to serve as Honorary Members of Council during their continuing presidencies of the Societies named: Mr. A. Jackson (Lincolnshire Iron and Steel Institute), Mr. G. H. Latham (Newport and District Metallurgical Society), Professor H. W. Swift, D.Sc. (Sheffield Society of Engineers and Metallurgists), and Mr. K. H. Wright (Staffordshire Iron and Steel Institute).

Mr. W. E. Bardgett and Mr. W. W. Stevenson continued to represent the Institution of Metallurgists.

In accordance with Bye-Law No. 10, the following names of Vice-Presidents and Members of Council due to retire at the Annual General Meeting, 1952, were announced at the Autumn Meeting, 1951:

Vice-Presidents—Mr. G. H. Latham, Mr. J. Sinclair Kerr, and Mr. H. H. Burton.

Members of Council—Dr. J. W. Jenkin, Mr. W. F. Cartwright, Mr. F. Saniter, Mr. T. Jolly, and Mr. R. A. Hacking, O.B.E.

No other Members having been nominated up to one month before the Annual General Meeting, the retiring Members are presented for re-election.

PRESENTATION TO THE INSTITUTE

Seven volumes of drawings relating to the patents granted to Sir Henry Bessemer have been presented to the Institute by his grandson, Mr. H. W. Bessemer. The volumes have been placed in the Library. These drawings are of considerable interest, and the Council wish to record their thanks to Mr. H. W. Bessemer for his presentation.

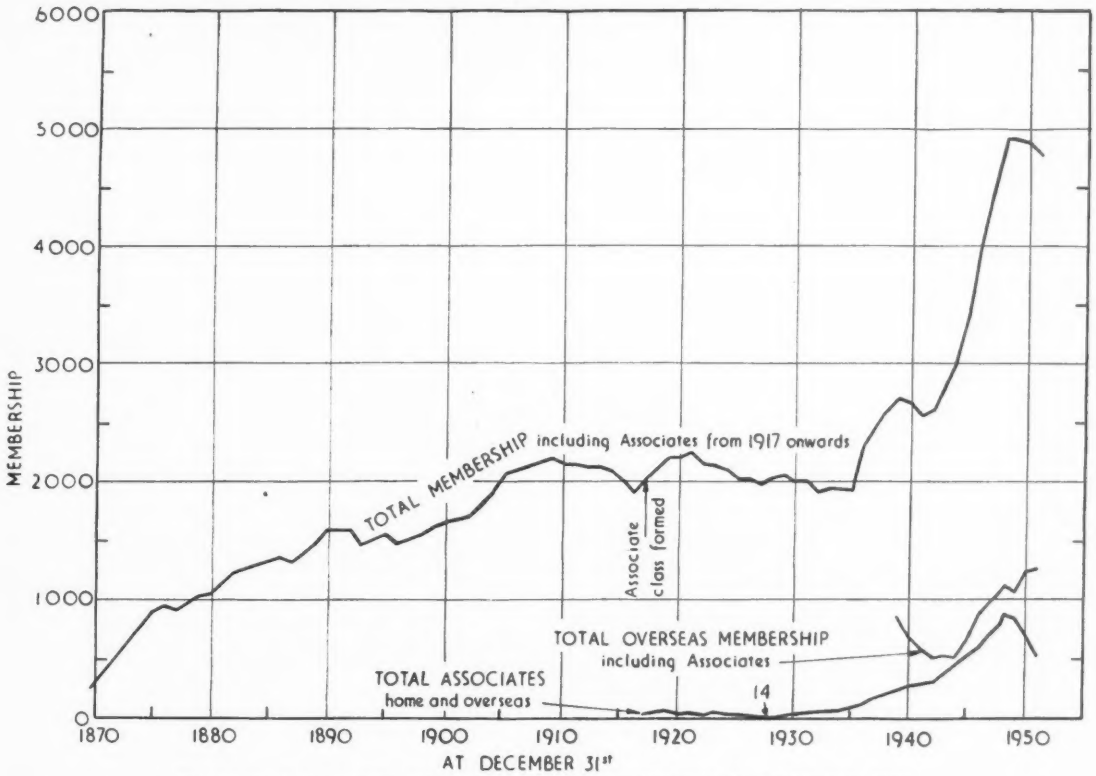

Fig. 1—Variations in Membership since the foundation of the Institute in 1869

AWARDS

The Bessemer Gold Medal for 1951 was awarded to Mr. Benjamin Fairless (President of the United States Steel Corporation) in recognition of his distinguished services to the iron and steel industry. As Mr. Fairless was unable to be present at the Annual General Meeting, Sir Charles Goodeve, O.B.E., F.R.S., made the presentation on behalf of the President during the General Meeting of the American Iron and Steel Institute in New York on 24th May, 1951.

The Sir Robert Hadfield Medal for 1951 was awarded to Mr. W. Barr (Colvilles, Ltd.) in recognition of his contributions to research in steelmaking.

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The Council wish to express their thanks to H.M. Minister in Austria, the Governor of the State of Styria, the Governor of the State of Carinthia, and the Rector of the Montanistische Hochschule, Leoben, for kindly agreeing to be Patrons of the Meeting; to the Council of "Eisenhütte Oesterreich" and the Chairman and Members of the Reception and Ladies' Committees; to the Council of the Institute of Metals; to the Governors (Landeshauptmänner) of Styria and Carinthia; to the Burgomaster and the City Council of Graz, the Senate of the Montanistische Hochschule, and the managements of the works who kindly invited Members and Ladies to visit them; and to the authors of papers and all others who so willingly collaborated in organizing the Meeting.

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Mr. P. A. Lee
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LIBRARY AND INFORMATION SERVICE

Joint Library

During the year under review, 11,617 publications were sent out on loan from the Joint Library. A further 279 textbooks were added to the Library. The Council again offer thanks on behalf of the Members to those authors and publishers who have made presentations to the Library.

Members are reminded that they are entitled to use the Lending Library. Books and periodicals are sent post-free to Members resident in Great Britain. By application to the Librarian, Members may borrow publications also from the Science Library, the Institution of Civil Engineers, and the National Central Library. Members both at home and abroad can, under certain conditions, be supplied with photostat and microfilm copies of articles; 46 photostats and 19 microfilms were made at Members' requests during 1951.

Information Service

The work of the Information Department is an important part of the service. The Department is prepared to answer enquiries from Members about the scientific and technical literature, but it is not its function to give the type of advice which comes within the field of the metallurgical consultant. The flow of enquiries during 1951, although not recorded, was well up to the volume received in preceding years.

CHANGES ON THE STAFF

Mr. Richard Elsdon, Librarian, retired on 31st December, 1951. He joined the Staff in 1904, was promoted Library Assistant in 1907, and was appointed Librarian in 1908. In 1937, when the Libraries of The Iron and Steel Institute and the Institute of Metals were amalgamated, he was appointed Librarian of the Joint Library. The Council wish to express their appreciation and thanks to Mr. Elsdon for his loyal service to the Institute and for his life-long and devoted work in the building up of the Library to its present important position.

The Council have arranged that from 1st January, 1952, Mr. A. E. Chattin, Assistant Secretary of the Institute since 1925, should be Assistant Secretary and Librarian, and that Mr. A. Post, who joined the Staff in 1946, should be Joint Assistant Secretary.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

The close collaboration between the Institute and the British Iron and Steel Research Association was continued throughout the year. The Association uses the Institute's Library, information, abstracting, and translation services, and member-firms may borrow books from the Library and use the information service without charge and in their own right. The Association continued to use the *Journal* as the principle medium for the publication of its research results and reports, such reports and papers receiving the same scrutiny and treatment as other papers submitted to the Institute. Accounts of the Association's activities appear from time to time in the News Section of the *Journal*.

The Council are glad to record their appreciation of the close collaboration existing between the two organizations.

RELATIONS WITH OTHER SOCIETIES

The good relations between the Institute and other scientific and technical societies at home and abroad have been maintained. This applies particularly to the Institute of Metals and the Institution of Metallurgists. Collaboration with the Sheffield Metallurgical Association and the West of Scotland Iron and Steel Institute was maintained in the same way as before.

Affiliated Local Societies

There are ten Affiliated Local Societies, as follows:

Cleveland Institution of Engineers
Ebbw Vale Metallurgical Society
Leeds Metallurgical Society
Lincolnshire Iron and Steel Institute
Liverpool Metallurgical Society
Manchester Metallurgical Society
Newport and District Metallurgical Society
Sheffield Society of Engineers and Metallurgists
Staffordshire Iron and Steel Institute
Swansea and District Metallurgical Society

Under the scheme of affiliation, the Institute and the Local Societies are able to be of mutual assistance without in any way diminishing their complete freedom of action. The Local Societies admit Members of the Institute to their Meetings; the Institute pays to each Local Society a capitation grant of 5*s*. per annum for each Joint Member, and any of these who are Associate Members of the Institute pay a reduced annual subscription of £1 11*s*. 0*d*.

Joint Meetings

Joint Meetings between the Institute (including the Iron and Steel Engineers Group) were held during the year with the Ebbw Vale Metallurgical Society, the Manchester Metallurgical Society, the Sheffield Society of Engineers and Metallurgists, and the Swansea and District Metallurgical Society. Joint Meetings were also held with the Sheffield Metallurgical Association and the West of Scotland Iron and Steel Institute.

A meeting to discuss five papers on "Internal Friction of Solids" was held in association with the Acoustics Group of the Physical Society and the Institute of Metals on Thursday, 15th March, at the offices of the Institute.

Metallurgical Societies Overseas

As the state of war with Germany was declared, by Order in Council on 9th July, 1951, to be at an end, the Council resolved at a Meeting shortly after that date that those of German nationality should again be eligible for election, and that the Verein Deutscher Eisenhüttenleute should be invited again to become a "Kindred Society." There are now nineteen of such "Kindred Societies":

American Institute of Mining and Metallurgical Engineers (Associate Member age limit, 33)
American Iron and Steel Institute
American Society for Metals
Association of Czechoslovak Mining and Metallurgical Engineers (Czechoslovakia)
Association des Ingénieurs sorti de l'Ecole de Liège (Belgium)
Associazione Italiana di Metallurgia (Italy)
Association Luxembourgeoise des Ingénieurs et Industriels (Luxembourg)
Australian Institute of Metals
Canadian Institute of Mining and Metallurgy
Indian Institute of Metals
Instituto del Hierro y del Acero (Spain)
Jernkontoret (Sweden)
Koninklyk Instituut van Ingenieurs (Holland)
Norsk Metallurgisk Selskap (Norway)
Société Française de Métallurgie (France)
Société Royale Belge des Ingénieurs et des Industriels (Belgium)

Verein Deutscher Eisenhüttenleute (Germany)
Verein Eisenhütte Oesterreich (Austria)
Verein Schweizerischer Maschinen-Industrieller (Switzerland)

Members of the Institute who are Members of, or are on the staffs of member firms of, any of the above Societies, if resident in the countries concerned, pay the following reduced subscriptions to The Iron and Steel Institute: Ordinary Members, £3 13*s.* 6*d.*; Associate Members, £1 11*s.* 0*d.*

Representation at Meetings

Sir Charles Goodeve, O.B.E., D.Sc., F.R.S., represented the Institute at the General Meeting of the American Iron and Steel Institute in New York on 24th May, 1951.

Lt.-Col. N. Watson, O.B.E., represented the Institute at the Meeting of the Verein Eisenhütte Oesterreich (Austrian Iron and Steel Institute) in Leoben, Austria, on 17th June, 1951.

Dr. A. H. Leckie, B.I.S.R.A., was the Institute's representative at the World Metallurgical Congress held at Detroit from 13th to 19th October, 1951.

Mr. K. Headlam-Morley, Secretary, was the representative of the Institute at the Meeting of the Société Française de Métallurgie in Paris from 22nd to 27th October and at the Meeting of the Verein Deutscher Eisenhüttenleute in Düsseldorf on 15th and 16th November, 1951.

Mr. R. Mather (President), Mr. G. Steel (Vice-President), Mr. T. Jolly (Member of Council), and Mr. K. Headlam-Morley (Secretary) attended the Meeting of the Instituto del Hierro y del Acero (Spanish Iron and Steel Institute) in Madrid from 10th to 15th December, 1951, as representatives of the Institute.

EDUCATION

Joint Committee on Metallurgical Education

This Committee held four Meetings during 1951. It received and considered comments on its "Recommendations on University Full-Time Degree Courses in Metallurgy," published in 1950. Of the 1000 copies of the Committee's Recommendations which were printed, 200 were distributed to Universities, Government Departments and other bodies concerned with higher teaching, and Research Associations, and approximately 700 have been issued in response to requests.

Mr. D. R. O. Thomas (United Steel Companies, Ltd.) agreed to become Chairman of the Committee in May, 1951, in succession to Mr. E. G. Lawford (Rio Tinto Company, Ltd.) who was obliged to resign owing to pressure of other business.

Dr. Leslie Aitchison was appointed Assessor to the Committee in May, 1951, when it was decided to conduct an enquiry into metallurgical education, with particular reference to metallurgical education other than at Universities. This enquiry is now being carried out.

Joint Committee for National Certificates in Metallurgy

At its four Meetings held in 1951, the Joint Committee considered and approved four schemes for Ordinary National Certificate Courses, two schemes for first year Courses at contributory centres, and six schemes for Higher National Certificate Courses (including one new 'sandwich' type scheme for the Higher Certificate with additional endorsement subjects).

The numbers of Courses in operation during 1951 were:

Ordinary Certificate Courses	28
Contributory Centre Courses	6
Higher Certificate Courses	17

The comparative figures of entries to final examinations in the years 1950 and 1951 are:

	1950	1951
Ordinary Certificate	281	314
Higher Certificate	62	110

and the numbers of Technical Colleges holding final examinations were:

	1950	1951
Ordinary Certificate	20	25
Higher Certificate	11	16

The numbers of certificates awarded were:

	1950	1951*
Ordinary Certificate	142	138
Higher Certificate	42	54

*The results for two Technical Colleges are not yet available.

HONOURS CONFERRED ON MEMBERS

The Council offer hearty congratulations to Members who have received honours or appointments during the year. Their names have been recorded in the News of Members columns of the *Journal*.

FINANCE

The Accounts for 1951 *are appended)*

(Figures for the previous year are printed in brackets for comparison.)

General Fund

The Balance Sheet at 31st December, 1951, is presented in the usual form. The total of the Accumulated Fund, Life Composition Fund, and various Reserves and Provisions, amounted to £40,930 (£40,044).

Income for the year ended 31st December, 1951, was £64,686 (£58,501) and normal expenditure was £61,180 (£52,604). After charging certain non-recurring expenditure, including the net deficit on the meeting in Austria and special expenditure on repairs and decorations, to which reference was made last year, the excess of income over expenditure transferred to the Balance Sheet was £718 (£5,897).

There has been some increase in expenditure under most headings, as follows: Gross Salaries, £20,506 (£19,534); Administrative Expenses, £7,468 (£5,187); Establishment Expenses, £3,888 (£3,070); Publications, £24,626 (£20,159); Library and Information Department, £1,686 (£1,197).

A new item included in the above is £551 for payment of rates, exemption from which has been discontinued. The increase in payment for abstractors' fees to £874 (£379) is due to the policy of arranging for more abstracts to be prepared by abstractors who are not on the staff.

The changes in most items of which the income is composed are small, with the exception that revenue from publications has increased to £39,178 (£33,350).

A separate Publications Account is submitted, in which details are given but, in accordance with usual practice, expenditure on salaries and overheads has not been charged. This account shows that the amount transferred to the Income and Expenditure Account and General Fund was £14,438 (£13,049).

Trust Funds

The Accounts of the Trust Funds are submitted in the usual form. In all cases income has exceeded expenditure, with the result that the amount standing in the accumulated funds has increased: Andrew Carnegie Trust Fund, £6,627 (£6,433); Williams Prize Fund,

£749 (£723); Bessemer Medal Fund, £42 (£32); Sir Robert Hadfield Fund, £15 (£10).

Investments

The market value of the investments of the General Fund at 31st December, 1951, was £31,673 and, therefore, was less than the cost, £32,982, at which they are taken into the Balance Sheet. The total figures for investments of the General and Trust Funds at 31st December, 1951, were as follows: Nominal value, £86,992 (£79,642); Cost, as included in the Balance Sheets, £76,066* (£68,760); Market value, £75,283 (£77,487).

* This figure includes £474.15*s*.0*d*. British Transport 3% Guaranted Stock 1978/88 at the figure of £400 at which it is included in the Balance Sheet of the Bessemer Medal Fund.

The following reply to the Loyal Address printed on p. 1 *has been received from Her Majesty's Secretary of State for Home Affairs.*

HOME OFFICE,
WHITEHALL
1st April, 1952

SIR,

I have had the honour to lay before The Queen the Loyal and Dutiful Address of the President and Council of The Iron and Steel Institute on the occasion of the lamented death of His late Majesty King George the Sixth and have received The Queen's Command to convey to you Her Majesty's grateful thanks for the assurances of sympathy and devotion to which it gives expression.

I am,
Sir,
Your obedient Servant
(*Signed*) DAVID MAXWELL FYFE

The President,
The Iron and Steel Institute.

THE IRON AND STEEL INSTITUTE

BALANCE SHEET, 31ST DECEMBER, 1951

General Account

1950	LIABILITIES			1950	ASSETS		
£	£		£	£	£		£
		Accumulated Fund :				*Furniture and Fittings*	Not valued
26,825		Balance as at 31st December, 1950	26,825			*Investments at Cost per Schedule*	
		Add Excess of Income over Expenditure for the year	718	28,010		(Market value at 31st December, 1951—£31,673)	32,982
			27,543			*Sundry Debtors and Payments in Advance :*	
		Less Transfer to Reserve for Ten Year Index	250	2,309		Stock of Paper	4,331
			27,293	5,637		Sundry Debtors	6,726
		Reserve :		697		British Iron and Steel Research Association	2,013
		Entrance Fees Reserve :		283		Current Accounts	181
5,978		Balance as at 31st December, 1950	5,978	1,098		Deposits and Payments in Advance	806
				5,915		Balances at Bank and Cash in hand	
		Current Liabilities and Provisions :		15,939		*Balances at Post Office Bank and Cash in Hand*	2,616
6,143		Sundry Creditors (part estimated)	9,043				16,673
1,692		Due to Life Composition Fund	370	29		*Joint Committee on Metallurgical Education*	2
11		Due to Sir Robert Hadfield Medal Fund	15				
32		Due to Bessemer Medal Fund	42				
50		Ablett Prize Fund Account	43				
190		Subscriptions in Advance	207				
943		Payments received in advance for Publications	1,158				
14		Due to Andrew Carnegie Research Fund	29				
		Sundry Provisions as at 31st December, 1950 :					
	600	Reserve for Ten Year Index	600				
		Transfer from Accumulated Fund	250				
			850				
	500	Library Account	500				
	1,000	Repairs, Decorations, and Equipment	1,000				
2,100			2,350				
		Bank Overdraft	3,129				
11,175			16,386				
£43,978			£49,657	£43,978			£49,657

Special Funds

1950				1950			
£	£		£	£	£		£
		Life Composition Fund :				*Life Composition Fund :*	
4,959		Balance as at 31st December, 1950	5,141		3,449	Investments at Cost per Schedule	4,939
182		*Add* Compounded during 1951	168			(Market value at 31st December, 1951—£4,083)	
					1,692	Due from General Fund	370
5,141			5,309	5,141			5,309
£49,119			£54,966	£49,119			£54,966

We have examined the above Balance Sheet of the Institute and found it to be correct.

FINSBURY CIRCUS HOUSE,
BLOMFIELD STREET,
LONDON, E.C.2
5th March, 1952

(*Signed*) W. B. KEEN & CO.,
Chartered Accountants

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1951

EXPENDITURE

1950 £	£		£	£	£
		Staff Expenses :			
19,534		Salaries		20,506	
		Less Contributions from :			
		Andrew Carnegie Research Fund	150		
		Institute of Metals	100		
		Institution of Metallurgists	60		
		Joint Committee on Metallurgical Education	300		
		Joint Committee for National Certificates in Metallurgy	500		
		Mond Nickel Fellowships Committee	250		
	1,360		1,360		
18,174				19,146	
336		National Insurance		330	
2,477		Staff Superannuation Fund		2,365	
20,987		Total Staff Expenses			21,841
		Other Administrative Expenses :			
1,065		Postage and Stationery		1,817	
572		Postage and Receipt Stamps		635	
1,225		Travelling and Entertainment : General		1,300	
963		Advertisement Collection		1,534	
515		Meetings :			
		General and Engineers Group	658		
		High Temperature Symposium	593		
		Buried Metals Symposium	30		
				1,281	
376		Telephones and Telegrams		343	
78		Insurances		90	
147		Audit Fee—1950		147	
		Interest on Overdraft		42	
246		Sundry Payments		279	
5,187					7,468
		Establishment Expenses :			
1,200		Rent		1,200	
		Rates		551	
1,446		Cleaning, Heating, Lighting, and Water		1,563	
286		Repairs and Decorations		424	
138		Office Furniture and Fittings		150	
3,070					3,888
		Publications : (*See* Publications Account)			
19,318		1951 *Journal :* Printing, Paper, etc.		21,152	
609		Other Publications : Printing and Paper		3,202	
232		Translations : Preparation		272	
20,159					24,626
		Library and Information Department :			
769		Library : Books and Binding		760	
49		Book Reviewers' Fees		52	
379		Abstractors' Fees		874	
1,197					1,686
50,600		*Carried Forward*			59,509

INCOME

1950 £	£		£	£
		Subscriptions :		
15,764		Current	15,895	
553		Arrears	528	
16,317				16,423
45		*Companies' Special Subscriptions*		45
		British Iron and Steel Research Association :		
6,000		Block Grant for Services other than Publications		6,000
		Interest on Investments (Gross) :		
1,089		General Fund	1,147	
141		Life Composition Fund	164	
1,230				1,311
		Post Office Savings Bank Interest		54
		Institute of Metals :		
850		Rent, Rates, and Services	950	
500		Library	500	
1,350				1,450
142		*Sundry Receipts*		83
		Publications : (*See* Publications Account)		
		1951 *Journal :*		
32,044		Revenue from Advertisements, Sales, and Amounts payable by British Iron and Steel Research Association	35,805	
932		Other Publications—Sales and Payments by British Iron and Steel Research Association	2,987	
374		Translations—Sales	386	
33,350				39,178
		Adjustments for 1950 :		
		Amounts overprovided : Indexes	43	
		Bound Volumes	66	
		Binding Cases	33	
67				142
58,501		*Carried Forward*		64,686

£	£		£	£
50,600		*Brought Forward*		59,509
		Miscellaneous :		
1,240		Historical Investigator : Honorarium and Expenses	1,249	
182		Contributions to Affiliated Local Societies	174	
250		List of Members		
		Education :		
	150	Joint Committee for National Certificates in Metallurgy	100	
	50	Joint Committee on Metallurgical Education	50	
	200		150	
		Grants :		
	1	Joint Committee for Materials and their Testing	2	
	25	British Standards Institution	25	
	16	Parliamentary and Scientific Committee	16	
	25	British Ceramic Research Association		
	5	Association of Libraries and Information Bureaux	5	
	60	Sir Robert Hadfield Medal Fund		
		Williams Prize Fund	50	
	132		98	
2,004				1,671
5,897		Balance carried down		3,506
£58,501				£64,686

£		£
58,501	*Brought Forward*	64,686
	Deficit on Special Meeting in Austria	1,074
	Repairs and Decorations (Special)	1,439
5,897	Balance brought down	3,506
	Rates : Liability, 1950 375	
	Less Contribution from Institute of Metals 100	
		275
	Excess of Income over Expenditure for the year	718
£5,897		£3,506

PUBLICATIONS ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1951

1951 *Journal*

1950 £	£	EXPENDITURE	£	£
15,072		Printing, Paper, and Blocks : Text and Advertisements	16,934	
250		Bound Volumes (estimated)	250	
600		Index (estimated)	600	
250		Binding Cases (estimated)	250	
2,456		Packing and Postage	2,376	
690		Reprints	742	
19,318				21,152
12,726		Balance transferred to Income and Expenditure Account		14,653
£32,044				£35,805

1950 £	£	INCOME	£	£
22,692		Advertising Revenue		25,890
	3,538	Sales : *Journal*—1951 Monthly Journal and Bound Volumes	4,018	
	923	*Journal* Back Numbers	896	
	1,014	Reprints and Blocks	740	
5,475				5,654
179		Binding Cases		230
3,698		Amounts payable by British Iron and Steel Research Association		4,031
£32,044				£35,805

Other Publications

£	£	EXPENDITURE	£	£
	363	Bibliographies	305	
	246	Special Reports	2,897	
609				3,202
323		Balance transferred to Income and Expenditure Account		
£932				£3,202

£	INCOME	£
932	Sales and Payments by British Iron and Steel Research Association	2,987
	Balance transferred to Income and Expenditure Account	215
£932		£3,202

ANDREW CARNEGIE RESEARCH FUND

BALANCE SHEET, 31ST DECEMBER, 1951

1950		LIABILITIES	£	£
		Amount of Original Fund, $100,000		21,241
		Add Amount Capitalized per last Balance Sheet		4,596
25,837				25,837
		Sundry Creditors:		
	585	Grants	768	
	10	Auditors' Fees	10	
595				778
2,600		Reserve for Travelling Scholarships		2,600
6,433		Accumulated Fund—Balance per Account annexed		6,627
£35,465				£35,842

1950		ASSETS	£	£
33,963		Investments at Cost per Schedule (Market value at 31st December, 1951—£35,042)		34,708
		Balances at Bank:		
	764	On Current Account	358	
	9	On Deposit Account	9	
	561	Post Office Savings Bank	575	
1,334				942
154		Income Tax Recoverable		163
14		Iron and Steel Institute: Current Account		29
£35,465				£35,842

ACCUMULATED FUND, 31ST DECEMBER, 1951

£		£
478	Grants	950
150	Contribution to General Fund on account of Salaries	150
10	Audit Fee	10
16	Sundry Expenses	5
6,433	Balance carried forward	6,627
£7,087		£7,742

£		£	£
5,790	Balance as at 31st December, 1950		6,433
	Income for Year ended 31st December, 1951:		
1,284	Interest on Investments (Gross)	1,205	
13	Interest on Deposits	14	
1,297			1,309
£7,087			£7,742

WILLIAMS PRIZE FUND

BALANCE SHEET, 31ST DECEMBER, 1951

1950	LIABILITIES	£
2,220	Capital Value representing Market Value of £3,000 3½% Conversion Loan on 21st September, 1926, when the Fund was inaugurated	2,220
723	Accumulated Fund—Balance per Account Annexed	749
£2,943		£2,969

1950		ASSETS	£	£
2,670		Investments at Cost per Schedule (Market Value at 31st December, 1951—£2,918)		2,769
		Balance at Bank:		
	116	On Current Account	37	
	157	Post Office Savings Bank	161	
273				198
		Sundry Debtor		2
£2,943				£2,969

ACCUMULATED FUND, 31ST DECEMBER, 1951

£		£
100	Awards	100
723	Balance carried forward	749
£823		£849

£		£	£
700	Balance as at 31st December, 1950		723
	Income for Year ended 31st December, 1951:		
121	Interest on 3½% Conversion Loan	121	
2	Interest on Post Office Savings Bank	3	
	Interest on 3% Defence Bonds	2	
123			126
£823			£849

BESSEMER MEDAL FUND

BALANCE SHEET, 31ST DECEMBER, 1951

1950	LIABILITIES	£	£	1950	ASSETS	£
£				£		
	Capital Value representing Market Value of £400 4% Debentures of L. & N.W.			400	£474 15*s.* 0*d.* British Transport 3% Guaranteed Stock 1978/88	400
400	Railway	400			(Market Value at 31st December, 1951—£366)	
32	Accumulated Fund—Balance per Account Annexed	42		32	Sundry Debtor—Iron and Steel Institute	42
£432		£442		£432		£442

ACCUMULATED FUND, 31ST DECEMBER, 1951

£		£	£		£
4	Medal	4	22	Balance as at 31st December, 1950	32
32	Balance carried forward	42		Income for Year ended 31st December, 1951 :	
			14	Interest on British Transport Stock	14
£36		£46	£36		£46

SIR ROBERT HADFIELD MEDAL FUND

BALANCE SHEET, 31ST DECEMBER, 1951

1950	LIABILITIES	£	£	1950	ASSETS	£
£				£		
	Capital Value representing Market Value of £267 11*s.* 2*d.* 3% Savings Bonds			268	£267 11*s.* 2*d.* 3% Savings Bonds 1955/65	268
268	1955/65	268			(Market Value at 31st December, 1951—£244)	
10	Accumulated Fund—Balance per Account Annexed	15		10	Sundry Debtor—Iron and Steel Institute	15
£278		£283		£278		£283

ACCUMULATED FUND, 31ST DECEMBER, 1951

£		£	£		£
13	Medals	3	43	Balance as at 31st December, 1950	10
88	Cost of Die for Medal			Income for Year ended 31st December, 1951 :	
10	Balance carried forward	15	8	Interest on 3% Savings Bonds	8
			60	Grant from Iron and Steel Institute	
£111		£18	£111		£18

THE IRON AND STEEL INSTITUTE

SCHEDULE OF INVESTMENTS AT 31ST DECEMBER, 1951
SHOWING NOMINAL VALUES, COST AND PRESENT MARKET VALUES

Nominal Value	Nature of Security	Market Value, 31st December, 1951	Cost
	GENERAL FUNDS OF THE INSTITUTE		
£ s. d.		£	£
2,197 7 0	3½% War Stock	1,769	2,161
1,324 7 4	3½% Conversion Loan	1,081	1,254
2,954 1 0	4% Consolidated Stock	2,648	3,176
12,242 19 3	4% Funding Loan, 1960/90	12,044	9,512
1,000 0 0	3% Defence Bonds (P.O. Register)	1,000	1,000
2,000 0 0	3% Savings Bonds, 1955/65	1,830	2,000
5,000 0 0	3% Do. 1955/65	4,575	4,972
2,000 0 0	3% Do. 1960/70	1,730	2,000
1,500 0 0	3% Do. 1965/75	1,258	1,500
4,854 2 0	British Transport 3% Guaranteed Stock, 1978/88	3,738	5,407
		£31,673	£32,982
	LIFE COMPOSITION FUND		
587 13 10	3½% Conversion Loan	480	513
205 15 6	3½% War Stock	161	212
681 13 0	4% Funding Loan, 1960/90	671	600
196 10 1	4% Do. 1960/90	194	231
2,615 11 2	British Transport 3% Guaranteed Stock, 1978/88	2,014	1,893
1,500 0 0	3% Defence Bonds (P.O. Register)	1,500	1,490
		£5,020	£4,939
	ANDREW CARNEGIE RESEARCH FUND		
	(Trustees: Sir Wm. Larke, K.B.E., The Hon. R. G. Lyttelton, and N. H. Rollason)		
6,897 14 11	3½% War Stock	5,553	6,896
800 0 0	Do.	644	794
2,693 12 0	3½% Conversion Loan	2,197	2,007
3,922 14 10	2½% National War Bonds, 1951/53	3,923	3,998
1,793 15 0	British Electricity 3% Guaranteed Stock, 1968/73	1,516	1,762
2,166 18 7	4% Funding Stock, 1960/90	2,132	2,643
500 0 0	2½% Defence Bonds (P.O. Register)	500	500
1,250 0 0	3% Do.	1,250	1,250
750 0 0	3% Do.	750	745
17,812 10 3	British Transport 3% Guaranteed Stock, 1978/88	13,716	10,863
1,000 0 0	3% Savings Bonds, 1955/65	915	1,000
2,250 0 0	3% Do. 1960/70	1,946	2,250
		£35,042	£34,708
	WILLIAMS PRIZE FUND		
	(Trustees: Sir Wm. Larke, K.B.E., The Hon. R. G. Lyttelton, and N. H. Rollason)		
3,452 15 7	3½% Conversion Loan	2,818	2,670
100 0 0	3% Defence Bonds (P.O. Register)	100	99
		£2,918	£2,769
	SIR ROBERT HADFIELD MEDAL FUND		
267 11 2	3% Savings Bonds, 1955/65	£244	£268
	BESSEMER MEDAL FUND		
	(Trustees: Desmond Lysaght, The Hon. R. G. Lyttelton, and N. H. Rollason)		
474 15 0	British Transport 3% Guaranteed Stock, 1978/88	£366	—

(*Signed*) J. MITCHELL,
Hon. Treasurer

(*Signed*) K. HEADLAM-MORLEY,
Secretary

We have examined the foregoing Balance Sheets and Income and Expenditure Accounts with the Books and Vouchers of the Institute and certify them to be correct. We have also verified the balances at the Bankers and the Securities for the Investments shown above.

FINSBURY CIRCUS HOUSE,
BLOMFIELD STREET, E.C.2
5th March, 1952

(*Signed*) W. B. KEEN & CO.,
Chartered Accountants

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

Presidential Address

The Development of the Tinplate Trade

WITH PARTICULAR REFERENCE TO THE INSTALLATION OF THE COLD-REDUCTION PLANT AT TROSTRE, LLANELLY

By H. Leighton Davies, C.B.E.

FOREWORD

IT HAS NOT come to me as a complete surprise that you proposed to elect me today as President of this great international organization—The Iron and Steel Institute.

I naturally feel very honoured and grateful for the very generous terms in which the proposal for my election has been submitted to this Meeting and received by the Members of the Institute.

During the whole of the 34 years that I have been a Member, I have taken a very keen interest in the Institute. I have known personally, or known of, most of the distinguished men who have occupied the office of President over a long period of years. I am consequently well aware of the fact that I am called upon to shoulder responsibilities that have hitherto been successfully carried by my predecessors.

It is with diffidence that I accept this office, and I assure you that I would not undertake it unless I were confident of the unstinted co-operation and sympathy of the Past-Presidents, Members of Council, and the Staff and Members of the Institute generally; even then, I am very mindful of the responsibility I have undertaken, and will make every effort to see that your confidence in me has not been misplaced.

I cannot help recalling on this important occasion in my life that my introduction to this Institute was by one of your Past-Presidents—a kind friend from my boyhood days, for whom I had great affection and regard—the late Sir Charles Wright. He made me a Life Member of the Institute as far back as 1918. His work for the Institute was most valuable and was done in a manner which I shall try to emulate.

You will, no doubt, forgive me if I also mention with pride my own father, Sir John Davies, who played some part in the affairs of the Institute, and a great part in the industrial life of South Wales, where, incidentally, I have been privileged to spend the whole of what I may claim to have been a very busy and active life. In 1910 I

This Address was presented at the Eighty-Third Annual General Meeting of the Institute, on 30th April, 1952, with the retiring President, Mr. R. Mather, in the Chair.

Captain Leighton Davies is Assistant Managing Director of the Steel Company of Wales, Ltd.

commenced work in the iron and steel industry at the Landore steelworks of the old Baldwins Company. It is of considerable interest, in view of the most recent commercial and technical developments in our industry, that, to the best of my knowledge, these works were what I may term the first fully integrated iron and steel plant in the whole country for the manufacture of sheet and tinplate bars only; for the Landore works had their own washery, coke ovens, blast-furnaces, hot-metal melting shop, barmill, blast-furnace-slag brickworks, foundry, engineering shop, and silica brickworks.

It is the background of long experience in manufacture that hall-marks the products of South Wales and, in particular, the tinplate industry, which, so far as the United Kingdom is concerned, is located exclusively in South West Wales.

My own experience has been gained in both the productive and commercial sides of the industry, and it seems fitting, therefore, that my Inaugural Address should have as its main theme this vital core of the industrial life of South Wales.

The first paper on the tinplate industry was given to the Institute by Mr. Flower, in 1886, and Sir Charles Wright dealt with th subject in his Presidential Address in 1931. But since the hand-operated method of making tinplate is now passing to complete mechanization it is appropriate that I should bring the history of the industry up to date by adding a further chapter.

I would, therefore, ask for your indulgence while I address you on this theme for a short time, tracing the developments that have taken place in the technical side of the industry, and making particular reference to the latest installation at the Trostre works of the Steel Company of Wales, at Llanelly.

Introduction

TINPLATE is mild-steel sheet (about 98% of its weight) with a coating of tin about $\frac{1}{1500}$ in. thick on each surface. It combines the strength of steel with the corrosion resistance of tin as a protective covering.

More than ever tinplate plays a leading rôle in our daily pattern of living, and it appears that we are approaching the stage where our health and existence depend on it; in particular in the form of cans as food containers. Canned food is now a basic requirement; in fact, a daily necessity. Millions of cans containing many varieties of foods are opened each day throughout the world, and likewise new cans are produced daily to be filled with fresh foodstuffs as replacements.

Tinplate thus enables many people to enjoy, out of season, such foods as vegetables, soups, fruits, meat products, fish, and many others.

The tinplate produced today is of a high quality to meet exacting standards, and is the result of metallurgical, chemical, and engineering research.

The manufacture of tinplate, or, more correctly 'tinned-plate,' can be divided roughly into two main processes:

(i) Manufacture of mild-steel sheet from the steel base
(ii) Tinning the sheet.

The flow diagram in Fig. 1 illustrates the breakdown of these processes.

The development of these manufacturing methods falls into three main periods:

(1) 300 B.C.–1727 A.D. Hammer reduction with hand pickling, tinning, and cleaning
(2) 1728–1925. Hot rolling in pack form with hand, machine, and automatic tinning
(3) 1926–present day. Rolling in strip form with automatic hot-dip tinning and electrolytic tinning.

HAMMER REDUCTION WITH HAND PICKLING, TINNING, AND CLEANING

Historical Data

300 B.C.	Cornish tin exported to Syria.
23 A.D.	Tin-coated vessels existed.
1260	Tinplates were being made in Bohemia.
1625	Tinplates made in Saxony (at Awre, near Segin Hutton).
1665	Tinplates made at Pontypool in Monmouthshire.
1690	Tinplates made at Bisham, near Great Marlow-on-Thames. The project failed.
1720	Tinplate works founded at Pontypool.

It is on record that in 1665 an enterprising soldier, Captain Andrew Yarranton, visited Dresden, where for many years tinplates had been made under the auspices of the Dukes of Saxony. From knowledge gained by studying the industry there, he was able on his return to this country to produce quite good-quality tinplates, using iron from the Forest of Dean and Cornish tin. He was, for some doubtful reason, prevented by Court injunction from continuing production.

In 1720 Major John Hanbury established a works at Pontypool, and as a result the trade gradually spread over Monmouthshire and Glamorgan and eventually to West Wales. In most instances tinplate manufacture was an addition to the work of the water-driven forges already existing on the banks of streams and generally near to deposits of iron ore and wood for charcoal.

The raw material produced by these forges was either 'balls' of wrought iron from the knobbling

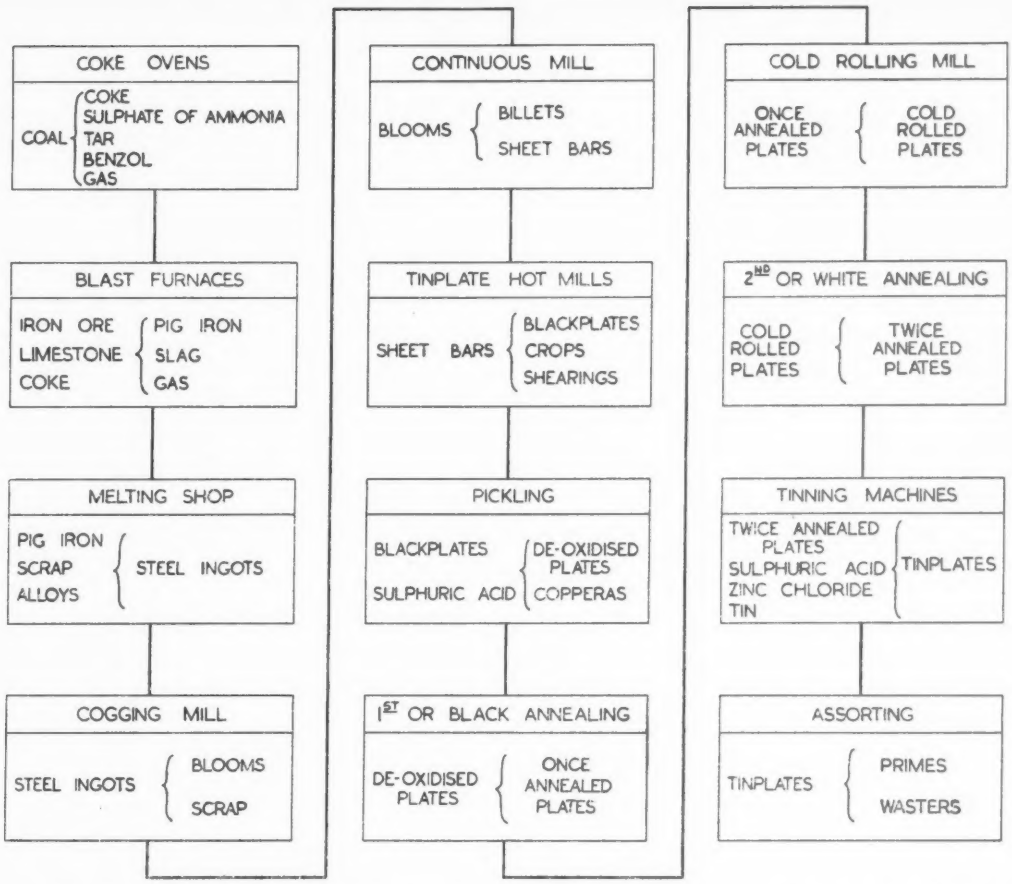

Fig. 1—Flow-sheet of steel and tinplate (pack-rolling) production. Data on the left relate to raw materials and those on the right to the products at each stage of manufacture

fires or small bars of puddled pig iron. These were heated in a furnace and hammered flat under a water-driven tilt-hammer or 'helve' until, after several reheatings and hammerings, they were doubled and dipped in a water tank containing sand and charcoal to prevent adhesion. These doubled pieces were stacked on edge in a furnace and after reheating they were taken in pack form and hammered until they had obtained the required thickness and dimensions. Allowance had to be made for the extra stretch of the inside sheets. It is on record that four men could hammer out 40–100 lb. of sheets (*i.e.*, one box) in 12 hr. Today, six men can produce 12 boxes in 1 hr.

After cooling, the sheets were cut to size with large hand-operated shears fixed to a table. The less perfect sheets were sorted out to be used as iron sheets. Those to be tinned were scrubbed with sandstone and immersed for about three days in a hot pickling liquid of fermented barley or rye water. During this period the sheets were frequently turned and agitated to remove the scale and oxide formed on the surfaces. Then followed a further sandstone rubbing, after which the sheets were stored in large vats of clean water to prevent rusting while waiting to be tinned. These processes are shown pictorially in Fig. 2.

Tinning and Cleaning

In early days the operation of tinning, and the vats and equipment used, varied considerably in minor points but were essentially the same throughout the trade. One early method was to immerse the plates one at a time into a bath of hot grease acting as a flux, and then to transfer them to another bath of molten tin. The baths were deep enough to take the whole width of the plate, and the tin bath contained about $1\frac{1}{2}$ tons of tin, which was kept molten by a furnace underneath, fed with wood fuel. A 'secret' of the trade was the introduction of a very small amount of copper into the tin, which, it was claimed, helped the fusion of tin with iron. Skill and experience had to be shown to obtain the correct temperature for tinning, as the bath had to be neither too hot nor too cold. After a certain time in the tin bath, the sheets were taken out one at a time and, if too cold, they were immersed into another small bath of tin, called the washpot. During this operation the surplus

SMELTING FURNACE
CHARCOAL FIRED REFINING FURNACE
CHARCOAL FIRED KNOBBLING FIRE
BALLS OF WROUGHT IRON
RE HEATING FURNACE
WATER WHEEL DRIVEN HELVE OR TILT HAMMER
FURNACE FOR VARIOUS RE-HEATING
SECOND AND THIRD HAMMER REDUCING
SOAKING BATHS WATER, SAND, CHARCOAL
RE-HEATING FURNACE
FINAL HAMMER TO SHEET
HAND SHEARS FIXED IN BENCH
SANDSTONE SCRUBBING
BARLEY RYE OR VINEGAR PICKLING
SAND AND WATER FRICTION HAND CLEANING
STORAGE IN CLEAN WATER TANKS
TINNING VAT
DRAINING TABLE
CLEANING TABLE (MOSS · SHARPS ETC.)

Fig. 2—Stages in the early manufacture of tinned plate by water-power hammer with hand pickling, tinning, and cleaning. Period from 1260 to 1727. The tin yield was 10–15 lb. per box

tin was removed with a hempen hand brush dipped in hot grease, and the plate was then immersed in another bath of grease, which helped to drain off the tin and brighten the surface.

The plates were then allowed to dry in a cooling pot and afterwards were cleaned by hand by rubbing with moss.

In a later method, the greasepot and tinpot were combined by dividing the surface of the tinbath by a longitudinal plate, thus allowing several inches of hot grease to be floated in one half. The first operation of the tinman was to place about 40 sheets on edge, one at a time, through the grease into the first half of this bath. These plates, being wet from the water bath in which they had been kept, agitated and helped the fluxing action in passing through the grease. The whole 'wad' of plates was then tilted over with a fork to the other side of the tinpot. They were then extracted with tongs and placed into an adjacent narrower bath of molten tin, called the 'soaking pot,' where they were allowed to remain while the tinman placed another 40 plates into the tinpot, or until the washman was ready to deal with them. The tinman took these sheets out of the soaking pot, placing them on a platform where the washman wiped both surfaces, one at a time, with a long hemp brush dipped in hot oil or grease, afterwards placing them into another pot containing molten grease kept hot enough to drain most of the surplus tin to the bottom. From this bath they were taken by boys or girls, and the 'list' at the lower edge was wiped off with a stick, after which they were stacked and cleaned by rubbing with sawdust and moss.

Similar operations for tinning sheets were probably used during the first 600 years of the trade, with additions and improvements, such as the division of the tinpot, the introduction of rolls to convey the plates from the greasepot, and the use of zinc chloride as a flux instead of grease. After about 1860 these operations gradually became more automatic.

HOT ROLLING IN PACK FORM, WITH HAND, MACHINE, AND AUTOMATIC TINNING

Historical Data

1728	Introduction of sheet-iron rolling in place of hammering
1745	'Greasepot' introduced to warm iron plates before tinning
1770	Coal substituted for charcoal in the smelting of iron ore
1775	Steam power first used in place of water-wheels
1806	Vitriol used instead of barley meal, etc., for pickling
1820	Guillotine shears invented
1829	Cast-iron pots first used in annealing process
1860	Rolls attached to pot to convey plates from greasepot
1865	Zinc chloride used as a flux instead of grease
1874	Introduction of pickling machine in place of hand labour
1874	Tinplate first made in U.S.A. (U.S. Iron and Tinplate Co., Demmler, Pa.; American Tin Plate Co., Wellsville, Ohio.) (both failed owing to strong Welsh competition).
1875	Siemens 'soft steel' used for tinplates instead of charcoal iron
1880	Use of Bessemer steel as an alternative to puddled bar iron
1883	Introduction of basic steel blooms in competition with Bessemer bars
1886	Invention of branning and dusting machines for cleaning
1891	McKinley Tariff Act came into force giving a protective tax of 2.2 cents per lb. on all tinplates imported into the U.S.A.
1892	Cleaning machines introduced
1900	Foreign bars imported for making tinplates
1904	Many tinplate works operating in U.S.A. Competition felt in South Wales
1905	Electricity used for power in various mills
1913	Tunnel annealing furnaces introduced. False bottoms used under pile of plates during annealing
1916	Invention of Thomas and Davies automatic combined feeding, pickling, swilling, tinning, and cleaning machine
1923	Automatic doubling machine in use in some mills
1930	'Aetna'-type cleaning machine popularized in this country.

It is generally agreed that in about the year 1728 the development of the rolling of sheets from bar superseded the process of hammering. The cycle of operations is shown diagrammatically in Fig. 3.

Power Supply

The motive power first used for hot rolling was obtained from the same water wheels that were used for actuating the old hammers or helves. A pair of cast-iron, surface-chilled rolls (one record says that stone rolls were first tried) about 15 in. dia. and 20 in. long was erected in housings. The bottom roll was driven from the water-wheel shaft while the top roll ran free. Pressure was applied as required through screws in the housings to the 'necks' or bearings of the top rolls (Fig. 4). By passing the heated bar or plate through the nip of these rolls and following the old system of doubling the elongated plate the required reduction in thickness was obtained. To regularize and control the speed of the rolls for sudden application and cessation of loads, a heavy flywheel was found necessary. The best working speed was found to be about 28–30 rev./min. With the water-driven mill four men produced approximately one ton of plate in 12 hr., that is, 2240 lb. compared with the 100 lb. referred to earlier.

The main development from this type of mill to the common mill now mostly used for producing pack-rolled plate, was the increase in the size of rolls, in some cases up to 28 in. dia. by 36 in. long. The average size now in favour is 24 in. dia. by 30 in. long, and two pairs of rolls are used, one for roughing or 'breaking-down' from the bar and the other for finishing.

Different arrangements have been tried, such as a 3-high mill, or cluster rolls (*i.e.*, two small working rolls backed up by one, two, or even more, larger and heavier rolls top and bottom), but they have been

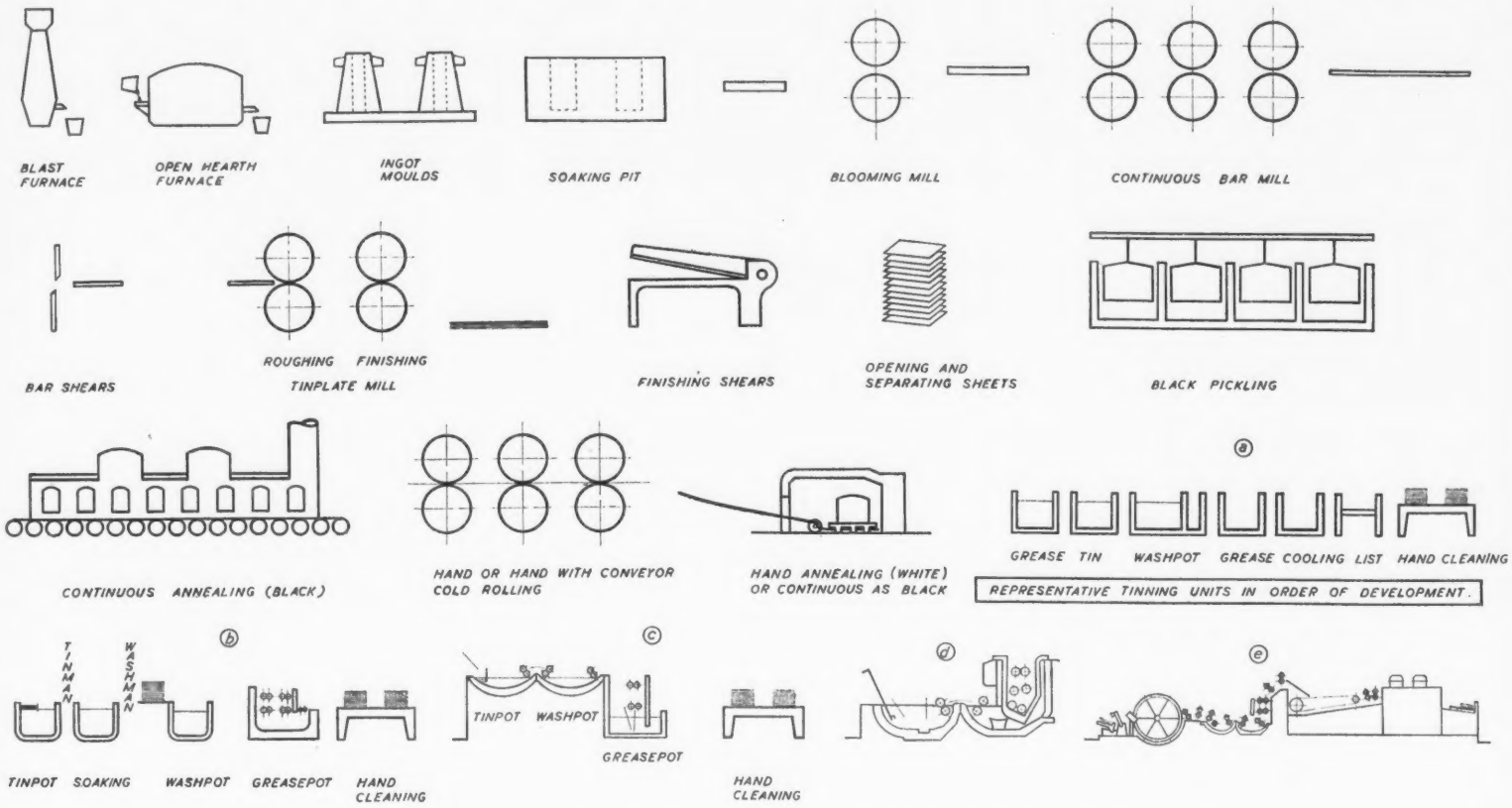

Fig. 3—Stages in the manufacture of tinplate by pack rolling with (*a*) hand tinning, (*b*) machine tinning, and (*c*) automatic tinning and finishing. Period from 1728 to 1925. The tin yield was 1–2 lb. per box

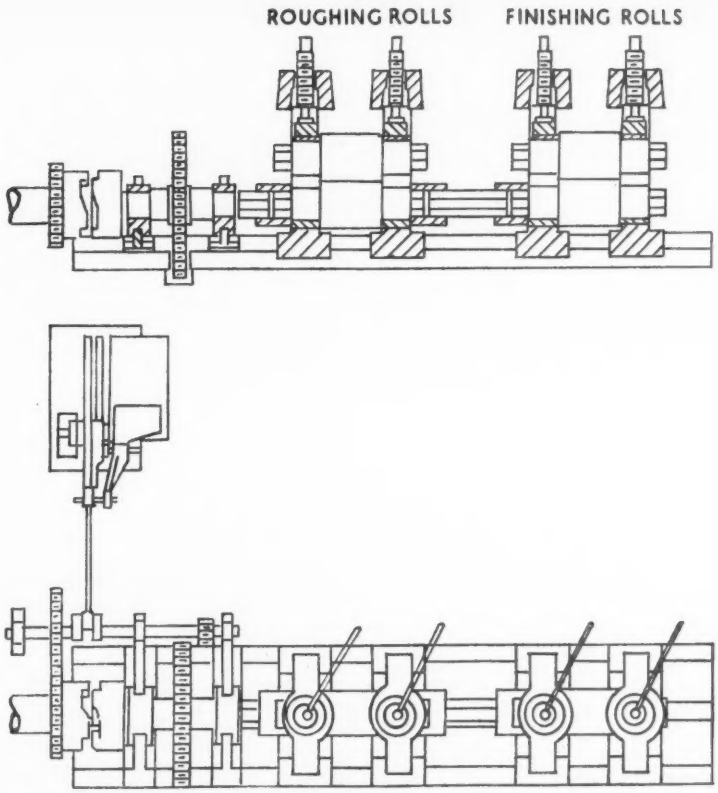

Fig. 4—Typical layout of double tinplate mill in use in South Wales

found to be less suitable than the old-type double 2-high mills for the varying range of thicknesses and sizes of plate required.

All the four main types of water-wheel, *i.e.*, overshot, undershot, breast, or Pelton, have been used as mill drives, according to the type of water supply available and the layout of the site, but the breast type has evidently been found the more suitable. As shown in Fig. 5*a*, the water flows on to the wheel just below the top and is carried down the near side to the tail race. From this type was next developed the vertical and horizontal water turbine (Fig. 5*b*).

Although the existence of water power was one of the main factors that determined the location of forges and tinplate works, the introduction of coal for steam raising encouraged other works to use steam engines for mill drives. Because they provided plenty of power at low speeds, especially with the use of a heavy flywheel, they became almost universally adopted. Nevertheless, the cheapness of water power kept many of the old water-wheels in commission into the 1930's.

Electricity has also been used, firstly with a motor directly coupled by multiple belts or ropes to the rim of a large wheel, which also acted as a flywheel, and, more rarely, through reduction gearing. In some instances, water turbines and electric motors have been combined, so as to maintain the power should the water supply fall short. In steam- or electric-driven double mills, a crew of six men produces 3½–4 tons of plates in an 8-hr. shift (or about 13,000 lb. in 12 hr., to compare with the figures previously given).

Heating Furnaces

Furnaces have varied little in the past 60 years. The type mostly used is reverberatory and coal fired. For each mill there are two furnaces built side-by-side, one for heating the bar from the cold and the other for the 'finishing parts' (Fig. 6).

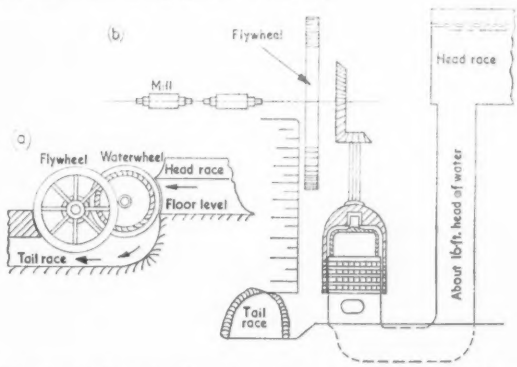

Fig. 5—(*a*) Popular breast-type water-wheel mill drive; (*b*) Old-type water-mill drive designed to generate 100 h.p. at 16 ft. head of water, and to drive one double 19-in. mill

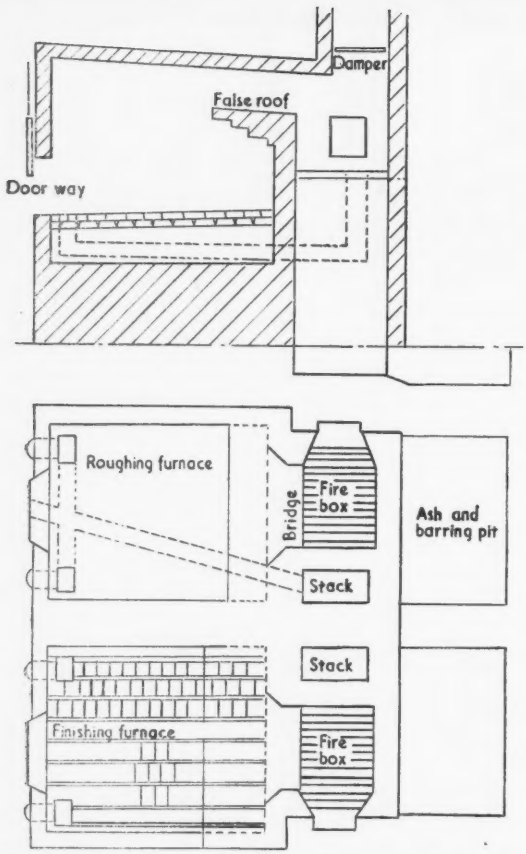

Fig. 6—Usual type of double-mill furnace. The flue and floor construction varies according to personal opinion

Oil and gas have now replaced coal in many works, resulting in better heating control and much improved working conditions for the operatives. The experienced furnaceman who controls the temperature of the iron by sight obtains very accurate results in manipulating the furnace.

Rolling

There are usually three methods of rolling plates from bar, known as the 3-part, 4-part, and 5-part systems, the latter being the one in general use. The process is illustrated in Fig. 7. From the mill, the plates, which are in various lengths and in packs of 4, 6, 8, or 12 sheets, according to the thickness or gauge required, are cut, after cooling, into the required sizes. The shears are generally of the 'crocodile' type, driven either by gears, or by cam and rocker action from the main driving shaft of the mill, or by separate electric motor and gears. Ends and sides are trimmed against properly placed guides and stops. Certain tolerances are allowed, according to gauge, for subsequent stretch in cold rolling.

At this stage the sheets in the pack stick slightly to each other and are separated by hand, one sheet at a time, and then pickled by the process known in the trade as ' black pickling.'

Pickling

The film of iron oxide, left on the sheets from the milling operation, is removed by immersion in almost boiling sulphuric acid at about 7% concentration and heated by steam. The sheets are then washed in a copious supply of cold water.

In the past few years there has been little development of pickling machinery except in the enlargement of plant to cope with greater output. For a long time a machine of a three-arm type was used, actuated by steam (Fig. 8*a*), the baths being above floor level. One bath contained the acid and another running water. A piston valve controlled the vertical motion, whilst the machine, through a system of stops and levers, automatically raised and lowered crates loaded with plates into the baths. The plates were thus agitated in the baths, one load being descaled while the other, which had previously been in the acid, was well washed with water. At the same time another crate was being loaded on a three-armed revolving table to be then swung round below the third arm of the pickling machine. When the iron oxide was removed from the plates in the acid tank, the three crates on the machine were swung round a third of a circle. As the washed one was detached and emptied, the freshly loaded one was attached, the cycle being repeated at a speed determined by the pickling operation.

The more modern Greys system, shown in Fig. 8*b*, is operated on an oval overhead runway, a section of which runs over acid and water tanks let into the floor in line. This section, on which the crates are suspended, is raised and lowered on the balanced rocker principle by a steam cylinder. At the end of the pickling operation the crates are raised clear of the tanks and are pulled forward by a horizontal steam cylinder, so that the crate just loaded is over the acid tank, the one just pickled is over the water tank, and the one washed is clear for unloading. Sometimes two acid tanks and two water tanks are used to ensure a cleaner plate.

Black Annealing

The pickled and washed plates are unloaded by hand and, after they have been examined to make sure that all oxide is removed, they are stacked in piles on cast-iron dishes, called annealing stands, over which a steel cover is placed and is then sealed with sand. The plates are then placed in an annealing furnace where they are soaked at a high temperature to soften the steel and to release the stresses set up during the previous hot rolling.

In most instances the annealing furnaces are of the reverberatory, coal-fired type, although gas, oil, and lately electricity, are being used with success. The old type of furnace was based on the ' batch ' principle, where a number of stands or ' pots ' of plates were charged into an empty furnace by means of a two-wheeled trolley with a long handle (Fig. 9). This trolley was manipulated by several men so that the pot could be levered up and run into its position in the furnace. When the furnace was filled or charged, it was sealed off, heated to the required temperature, and then allowed to cool somewhat before it was

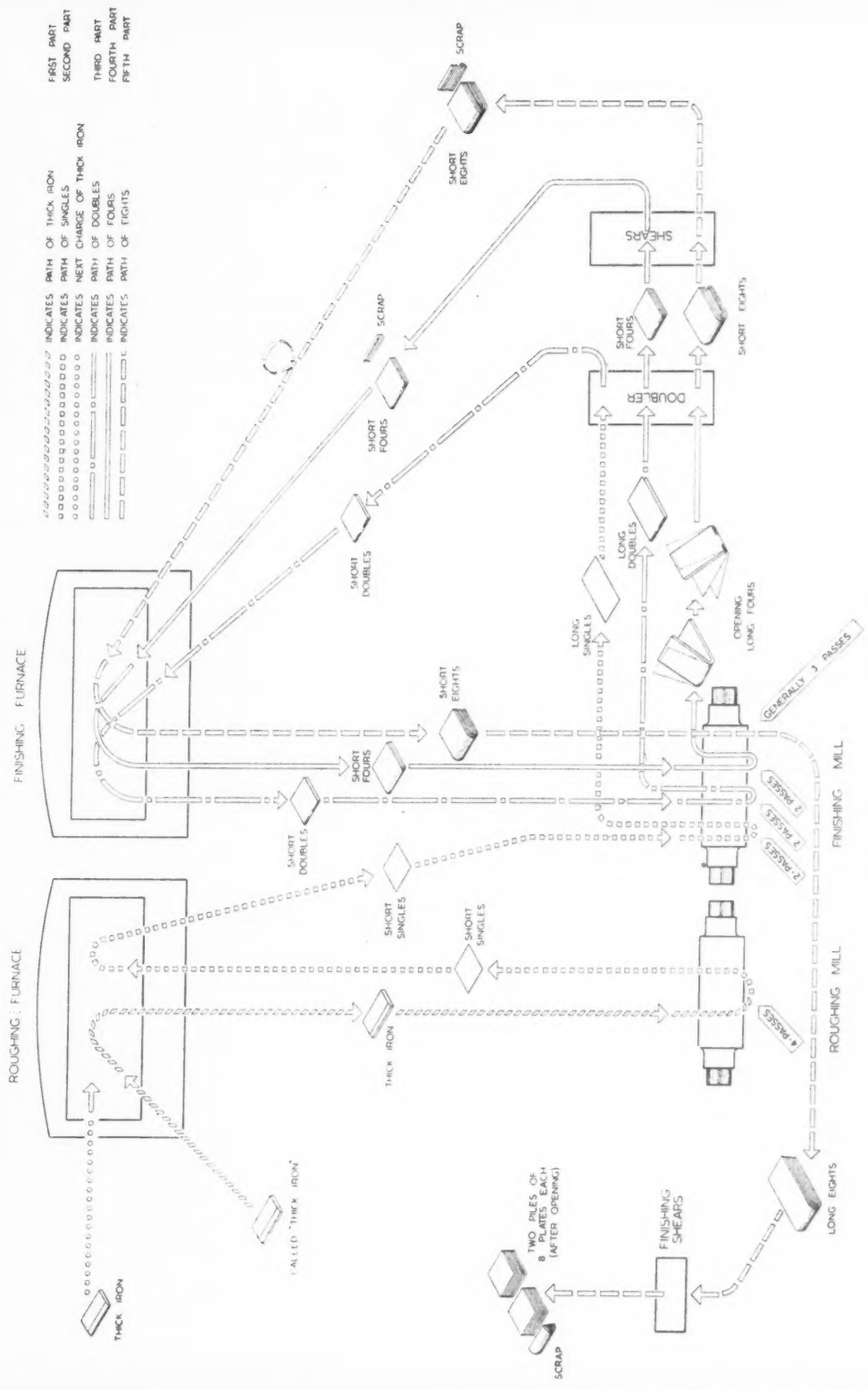

Fig. 7—Diagram showing the production of blackplate by the 2-stand, 5-part system

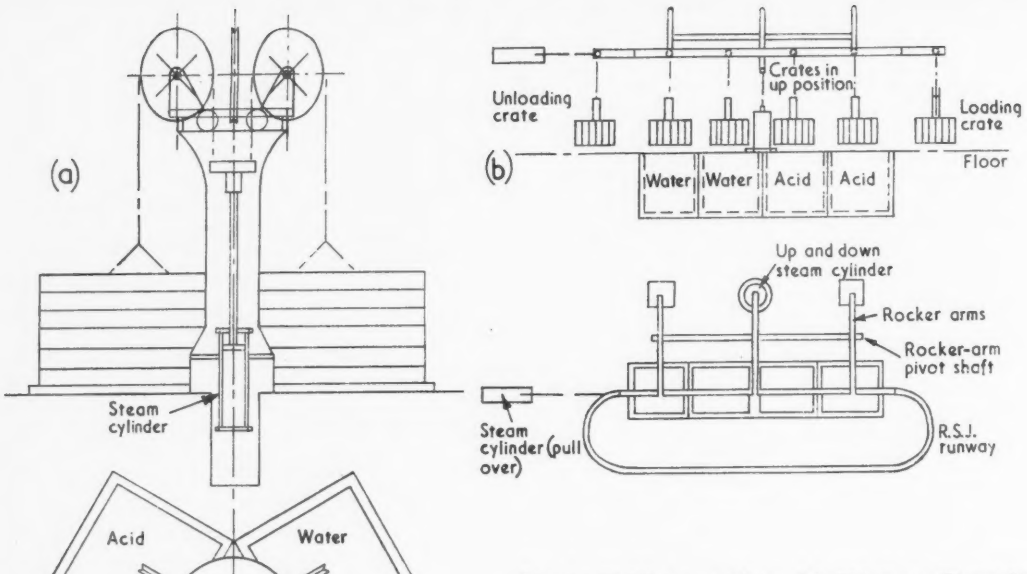

Fig. 8—Pickling machines: (*a*) Old type; (*b*) modern (Greys) type

opened. The pots were taken out by trolley and another batch was charged.

Figure 11 illustrates a more modern type of furnace built in the form of a tunnel, through which trolleys run on rails. As a laden trolley of pots enters the furnace the whole line of trolleys is pushed one trolley-length forward. The fire-grates are at the sides of the centre portion forming the hot zone and the stacks are at the entry end. The motive power is sometimes applied by hydraulic ram but more frequently by a system of pulleys and wire ropes from an existing overhead electric crane.

Apart from annealing the plates, it is desirable in this process to reduce any surface oxide that may have formed. A practice of introducing a non-oxidizing atmosphere, such as coal-gas or nitrogen, into the pots, generally during the cooling-off period, has resulted in a plate known as 'silver finish,' almost free from oxide. After cooling below oxidizing temperature the cover is removed from the pile of plates.

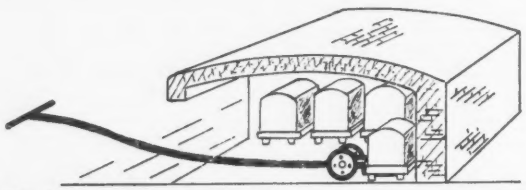

Fig. 9—Old type of annealing coach for hand charging

Cold Rolling

In cold rolling, the plates are passed singly through a series of three pairs of chilled-cast-iron rolls under great pressure, which impart a highly polished and dense surface to the plate, so that it does not absorb too much tin.

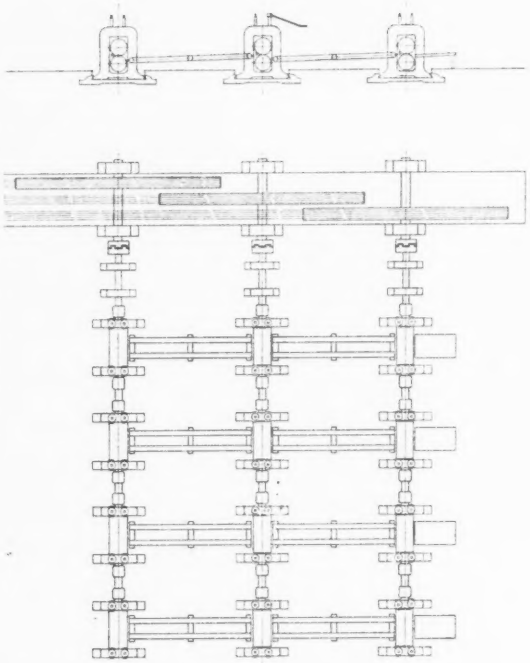

Fig. 10—Layout of cold rolls

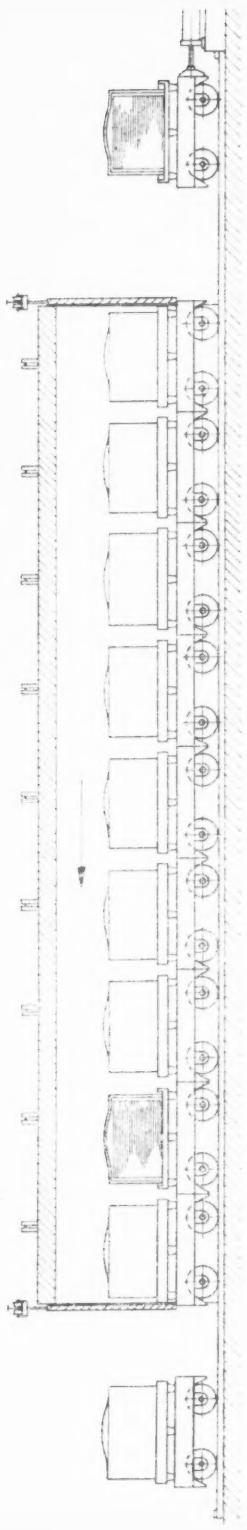

Fig. 11.—Modern tunnel-type annealing furnace

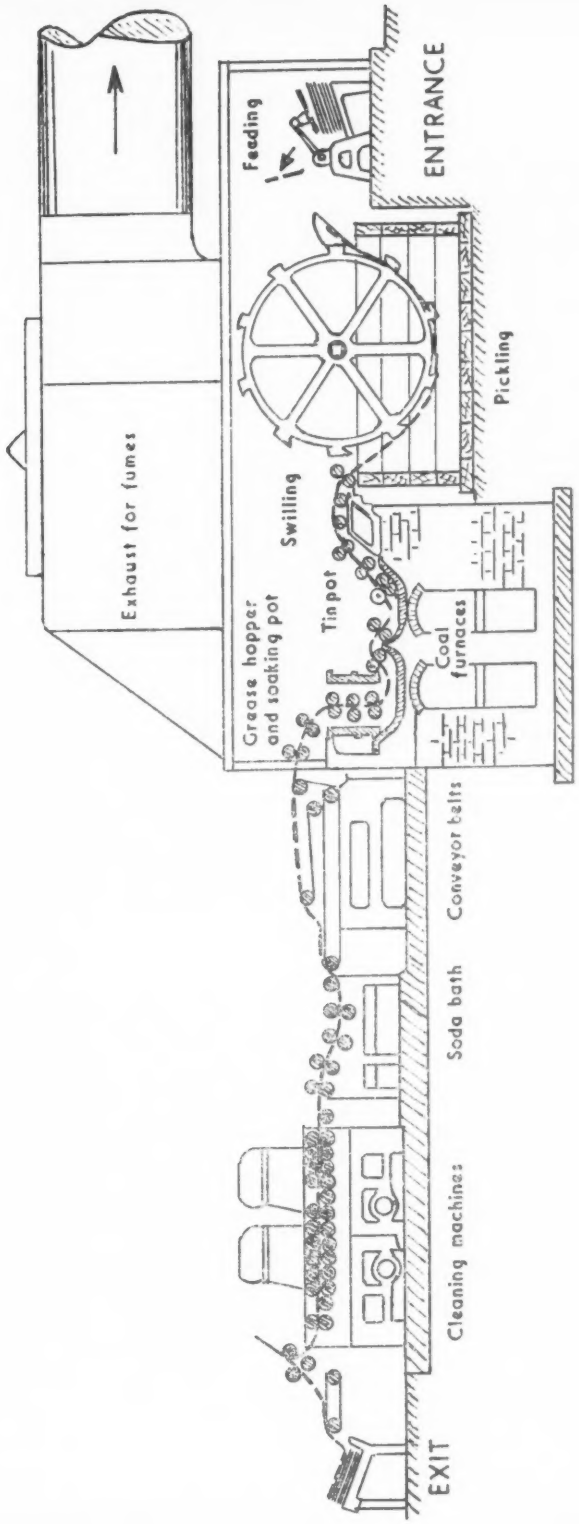

Fig. 12.—Cross-section of the Thomas and Davies (Melingriffith) automatic combined feeding, pickling, tinning, and finishing machine

Several years ago cold rolls were often attached to the end of a train of hot-mill rolls for use as stocks required. As mill outputs increased, separate units were installed in which a steam engine drove three trains of rolls at about 50–60 rev./min., through gearing or rope belts (Fig. 10). The roll housings are similar to hot-mill housings, though lighter, and each is fitted with two pressure screws, which are tightened by hand with long-shafted heavy iron spanners. The plates are fed by hand, one at a time, into the first pair of rolls and carried to the second and third where the operation is repeated. More recently, belt conveyors have been introduced between the trains to avoid this carrying.

The hardness caused by cold rolling has to be relieved by re-annealing the plates, which makes them more supple and pliable for easy manipulation by the fabricator. The system is almost the same as the first annealing, except that the time in the furnace is shorter and the temperature is lower. In many works the same furnace is used, at different times, for both first and second annealing, known in the trade respectively as 'black' and 'white' annealing. After cooling from the second annealing and after having been once more pickled to free them of oxide formed in the annealing process, the plates are ready for tinning.

Tinning

The four main types of hot-dip tinning machine at present in use are (1) Players, (2) Abercarn, (3) Thomas and Davies (Melingriffith), and (4) Poole Davis (Aetna Standard).

The latter two are almost fully automatic, the feeding and pickling processes being part of the machine, but with the other two types a separate pickling plant, as already described, is used. In the Players and Abercarn types the plates, after white pickling and washing, are not allowed to dry and become stained, but are kept in large vats of clean water. They are taken from these by hand and fed into the entry end of the tinning machine, from which they are conveyed through the fluxing, tinning, and cleaning sections by means of rollers and guides.

With the Thomas and Davies (Melingriffith) machine, illustrated in Fig. 12, the operations of feeding, pickling, swilling, tinning, and cleaning are all combined and automatic. Whereas in the old types of machine two or three plates travelled through side by side, this machine has four sideways or six endways. Dry plates are stacked by hand on to the four (or six) receiving tables from each of which they are lifted by means of a rubber sucker. Sand is sprinkled between the plates before they are stacked so as to

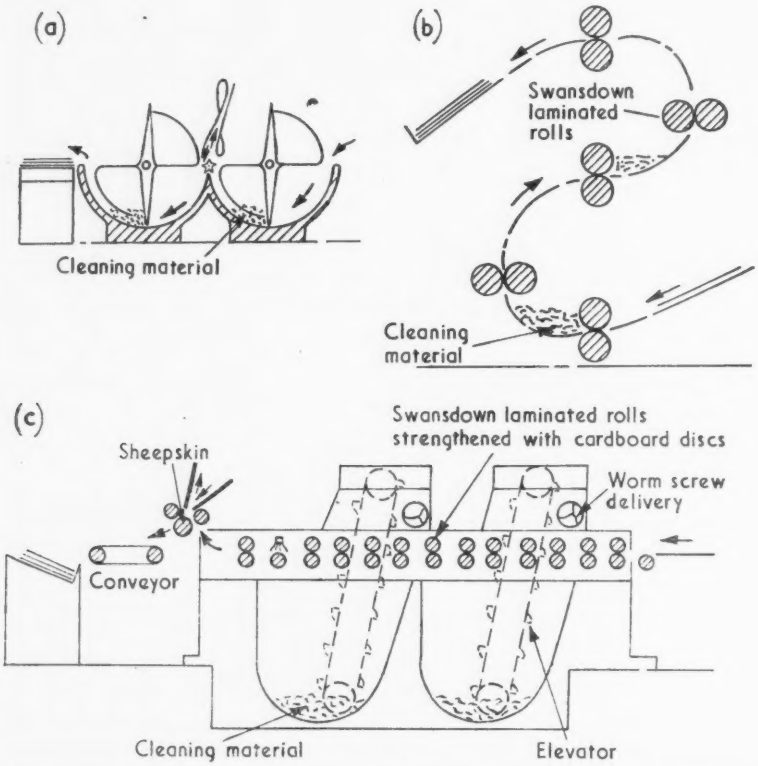

Fig. 13—Types of tinplate cleaning and polishing machine: (*a*) Old-type Melingriffith; (*b*) S-type (not extensively used); (*c*) modern Aetna or Renco (extensively used)

prevent more than one sheet being lifted at a time. The suckers on semi-rotary arms convey the sheets and release them into the lead-lined pickling bath, which contains sulphuric acid at about 10–15% concentration and is steam heated to nearly boiling point. By the time the plates emerge from this acid tank they are free from all oxide, and the surplus acid is squeezed off with rubber rollers, which also convey the plate through the washing section, where water jets play on both top and bottom surfaces of the plates, washing them clean of all acid.

The tinning section comprises two semi-circular cast-iron baths of molten tin, heated by coal, gas, oil, or electricity. The plates, after swilling, are conveyed into the first bath of molten tin through a solution of zinc chloride to provide an initial layer of flux on the surface of the tin, and then by a system of rolls and guides into the second or soaking bath. Here they pass through the tin and emerge vertically through three pairs of special hard-steel rolls running in a bath of molten palm oil. It is at this point that the amount of tin on the plate is controlled. The oil keeps the tin on the sheets molten whilst the rolls, by capillary attraction, take off tin from the plate surfaces. Asbestos or soapstone brushes on the rolls wipe off the surplus tin before the same spot on the revolving roll touches the plate again. The tin thus removed falls down through the oil to the tinpot below. The quantity of tin allowed to remain on the plate is controlled by adjusting the pressure of the brushes on the rolls.

Cleaning and Polishing

As the plates leave the palm oil they carry an oil film on the surfaces, which must be removed. In all cleaning machines an absorbent medium is used, such as hardwood sawdust, bran, and wheatings, to which is added a small amount of material such as calcium sulphate (' pink meal '). As this medium sucks up the oil and eventually becomes saturated with it, constant replenishment is necessary.

One of the earliest types of cleaning machine, shown in Fig. 13*a*, comprised two semi-circular tanks covered at the bottom with a layer of cleaning material. Plates were conveyed through the first tank by large revolving discs with pads on the periphery (somewhat similar to those in the pickling section). As each plate came out of the first tank it was turned over and dropped into the second tank where the same operation took place. On leaving the machine the plate passed through a series of polishing rollers covered with sheepskins, which dusted and polished the surface.

Another type of machine, shown in Fig. 13*b*, used the ' **S** ' principle, the plate passing through two curved dishes, one above the other, in which rested the cleaning medium. Conveyance was by rollers, and the system was similar to the side-by-side method but did not take up so much room.

The Aetna type of machine, shown in Fig. 13*c* as attached to the Thomas and Davies machine, is the one most universally used. It is sometimes preceded by a soda bath to help remove the oil. This bath contains a hot solution of soda and soap, through which the plates are conveyed by means of guides and rollers and then on to the cleaning machine as quickly as possible, before they have time to dry and become stained. The machine is of horizontal construction, and the plates are conveyed through it by a series of rollers, not touching one another, but over and through which the cleaning medium is kept in motion. Screw conveyors gather the material at the bottom, from which it is raised by chain-cup elevators, and it is delivered at the top level again by further screw conveyors. The rolls are built up from swansdown buffing discs compressed into laminated form and are driven by endless chains on the outside of the machine. Alternate rolls rotate at different speeds, the top roll in one pair travelling faster than the bottom, while in the next pair the bottom roll turns more quickly than the top, thus subjecting both sides of the plate to a series of brushing operations. As the plate leaves this machine most of the cleaning medium is brushed off by static brushes under which the plate passes ; it is then polished by travelling through several high-speed sheepskin and buffing-disc rollers.

Piling, Assorting, and Packing

The finished tinplates are piled and then conveyed to the inspection or assorting tables, where they are turned over singly by hand. They are examined carefully for defects and sorted into grades, such as primes, seconds, wasters, waste-waste, light- and heavy-gauge sheets, and menders. They are then counted into the required number of sheets, weighed, and packed ready for shipment. For many years all tinplates were packed in birch, elm, or other hardwood boxes and also in cardboard containers, in quantities of about 2 cwt. per box. With the development of road transport and the use of overhead cranes and power lifting trolleys, packing in bulk of ½- to 1-ton stands has generally superseded the former practice. The plates are packed on wooden stillages and bonded down by wire or strap bonding machines, the whole being covered with cardboard or, when the plates are for export, with a thin mild-steel sheet casing, which is strapped to give it further protection during transport and storage.

It is sometimes more economical to manufacture tinplates in sizes two or three times the actual size required by the purchaser, such as 30 by 20 in. for an order of 20 by 10 in. Such plates are tinned in the large size and are then slit into the smaller size by means of a rotary shearing machine. This machine is sometimes automatic but it is more generally fed by hand. The plate, guided at one side, is pushed into the nip of the cutting discs, which are fixed on a pair of revolving shafts one over the other. These convey the plate through the machine while the discs slit it into the required sizes.

Wasters

In each stage of manufacture there is the possibility that wasters may occur, and close and constant supervision is necessary to avoid them. When it is appreciated that wasters may result from over 50 different causes and that during its manufacture the plate is separately handled more than 100 times, by

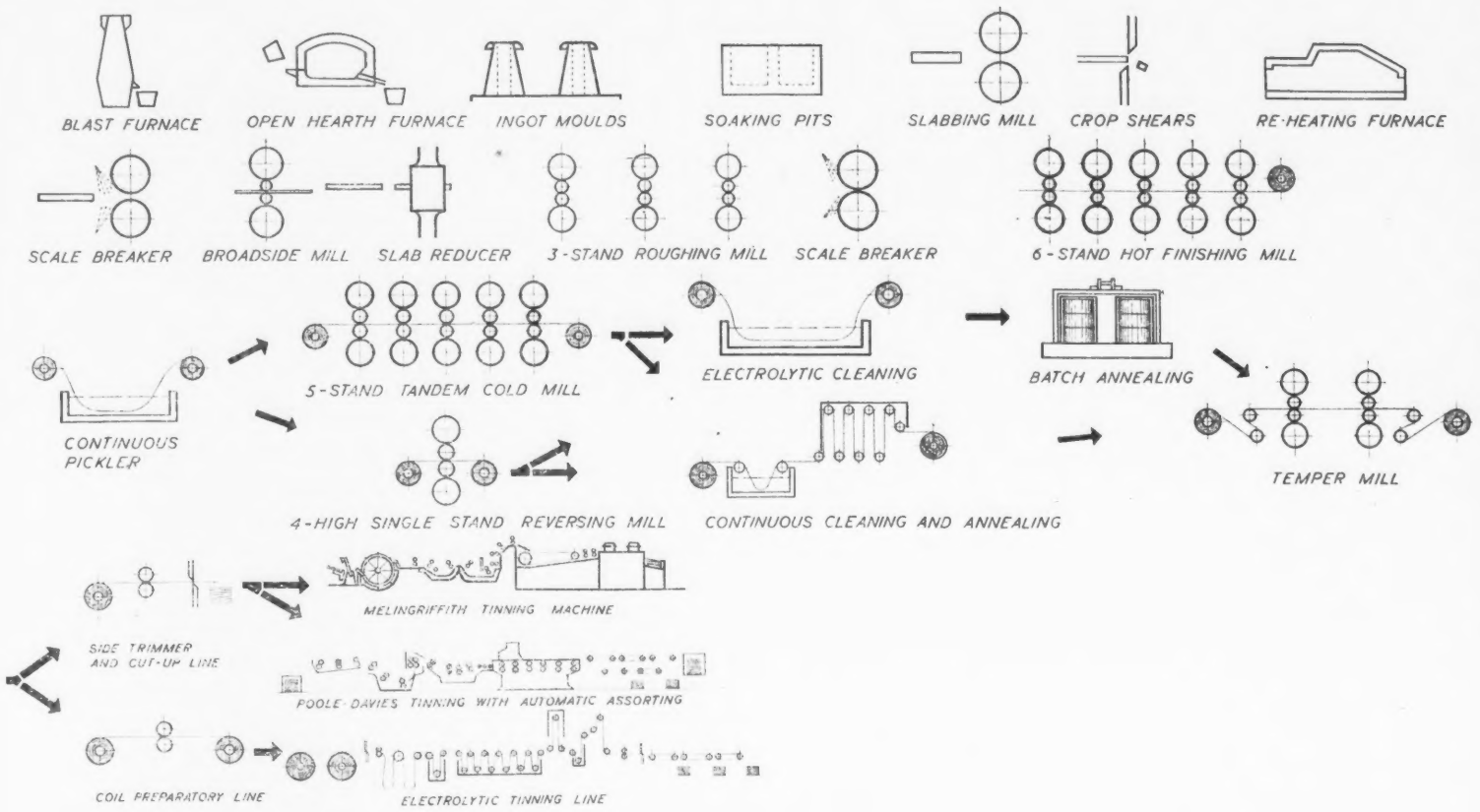

Fig. 14—Stages in the manufacture of tinplate by the strip-rolling process with automatic tinning. Period from 1926 to 1951. The electrolytic tin yield is 0–1 lb. per box

many individuals, the enormous influence of the human element and the impossibility of the total elimination of wasters are apparent.

The following table shows the numbers of defects that may occur in various Departments, leading to the possibility of wasters :

Faulty steel	7	Annealing	9
Hot mills	16	White pickling	6
Cold rolls	6	Tinhouse, assorting,	
Black pickling	5	and packing	12

Generally, with the exception of those caused by faulty steel, the wasters tabulated are the result of some feature of the process itself, a lack of proper attention on the part of the operator, or of some defect in one particular unit of equipment. However, the repeated production of wasters through one cause compels a thorough investigation, and a remedy can generally be found.

ROLLING IN STRIP FORM WITH AUTOMATIC HOT-DIP AND ELECTROLYTIC TINNING

Historical Data

1926	Strip rolling for tinplates developed in the U.S.A.
1935–38	Manufacture of tinplates by the cold reduction of strip introduced into this country by Richard Thomas and Co., Ltd., Ebbw Vale
1938	Electrolytic tinning of plate and strip being developed
1946	First continuous electrolytic tinning line erected in Great Britain by Richard Thomas and Baldwins, Ltd., Ebbw Vale
1947	Start of erection of second cold-reduction plant for tinplates at Trostre by Steel Company of Wales, Ltd.

Continuous Rolling

The outstanding development in sheet rolling in recent years has been the use of continuous mills for rolling both hot and cold steel strip sheet suitable for tinplate gauges (Fig. 14).

This method, first established in America, was first operated in this country in 1938.

The two main types of strip mill in use are tandem mills and reversing mills.

Tandem Mills are a series of individual stands of rolls synchronized to operate in line and used in both the hot and cold rolling processes. These large units need a great deal of room to operate, and the capital cost is high, but they produce a large output of good-quality plate very economically and effectively.

The Reversing Mill is a single stand of rolls, 4-high, whose rolling direction can be reversed. In some cases only the rolls are driven and in others the rolls are idle and the sheet is drawn through (as in wire-drawing), the coilers being alternatively power driven.

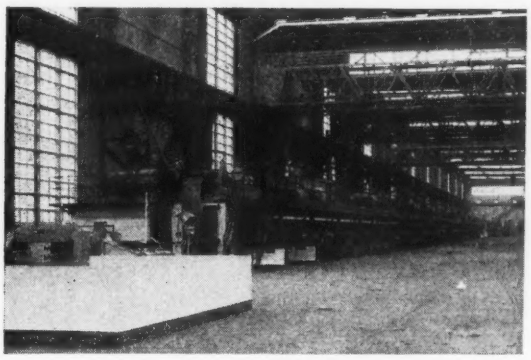

Fig. 16—View of the continuous pickling line at the exit-end looping pit

Another variation combines both, with the rolls and coilers both under power. This type of mill is less expensive than the tandem mill ; it takes up comparatively little room and is essentially suitable for the small-output plant.

The process for producing the raw material for a strip mill is the same as for the pack mill up to the stage of the blooming mill. For strip rolling the product of this mill is in the form of slabs 3–6 in. thick and 20–40 in. wide (instead of being rolled into bars $\frac{1}{2}$–$\frac{3}{4}$ in. thick, 8–12 in. wide and 15–16 ft. long). These slabs are hot rolled in a continuous mill down to a thickness of about 0·074–0·083 in. and are finished coiled in strip form, the width of the strip being approximately the length required for the finished tinplate.

Pickling

The next operation is pickling to remove the iron-oxide scale from the strip, formed during the preceding hot-rolling process. In the latest plant now being installed in this country at Trostre, Llanelly, by the Steel Company of Wales, Ltd, the pickling is carried out in a continuous pickling line as illustrated in Figs. 15 (folder) and 16.

Coils weighing 15,000 lb., 0·083 in. thick and up to 38 in. wide, are loaded on to the conveyors. After uncoiling and scale breaking the ends are trimmed in the upcut shears. To enable the operation to be continuous the trailing end of one coil is attached to the leading end of the following coil by electric welding or by stitching. The looping pit acts as a reservoir to provide time for welding and stitching, and the maximum speed to this point is 1000 ft./min., whilst the maximum speed through the acid tanks is 500 ft./min.

The strip then passes through five acid tanks, where the oxide scale on the strip is removed by the action

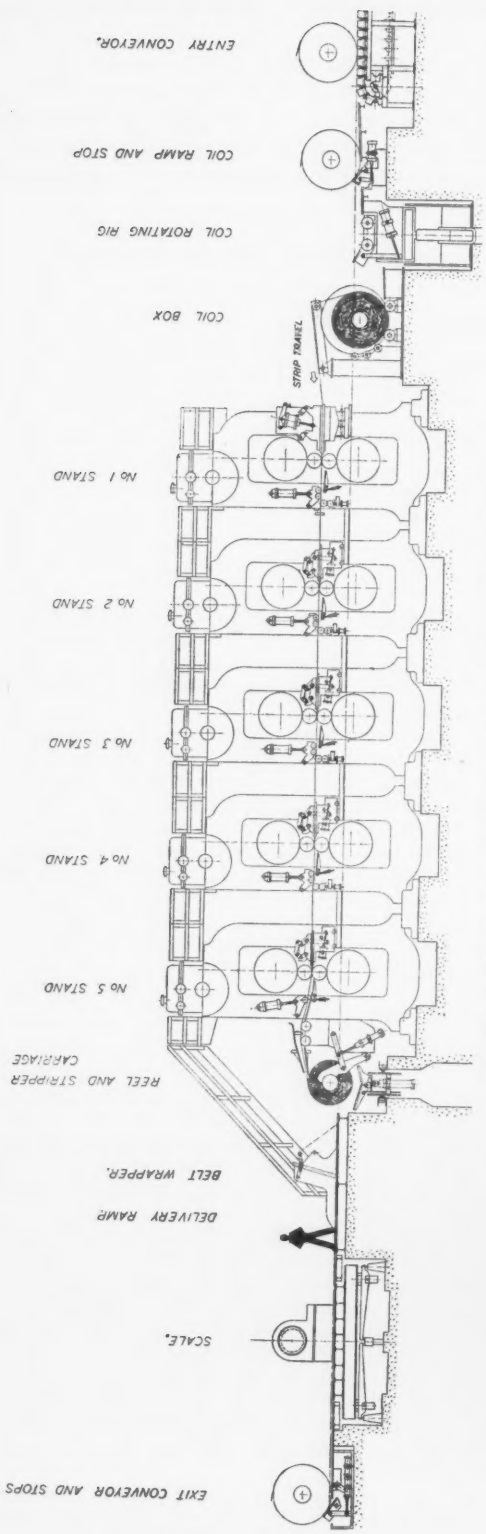

Fig. 17—Diagram of the 4-high, 5-stand tandem tinplate cold mill

of sulphuric acid. Beyond these tanks are two water-spray tanks, cold and hot respectively, in which all adhering acid is washed off, and the strip is dried with the help of steam-heated air.

To provide time for the final operation, the strip then enters another looping pit, after which the stitch join is cut out and the edges of the coil are side-trimmed. The weld is left in, so that the strip, on recoiling, weighs 30,000 lb. During recoiling, it is coated with hot palm oil and is finally ejected over an automatic weigher on to a coil conveyor for transfer to the mill.

Cold Reduction

The coils are loaded from the pickling tanks on to the entry conveyor of the 5-stand cold-reduction mill (Figs. 17 and 18). This conveyor feeds a rotating rig which, in turn, guides the leading end of the coil into the guides of No. 1 stand and eventually the coil itself into the coil box, where it is paid off into the mill.

The mill consists of five 4-high stands and a Klein-type tension reeler, together with the necessary driving, screwdown, and control equipment. Each stand is driven by a D.C. motor through a pinion stand. The total output of the mill motors is 18,250 h.p., and the maximum speed of the fifth stand is 4500 ft./min. The cast-steel housings each weigh about 100 tons and have 53-in. dia. × 47-in. long back-up rolls, also of cast steel. The forged-steel work rolls are 21 in. dia. × 48 in. long.

During the rolling process the strip is lubricated with palm oil and passes through wood-lined air-operated wiper boxes before entering the nip of the rolls. The rolls are water-sprayed to dissipate the large amount of heat generated during cold reduction, and to control their temperature, the resulting mist being exhausted into a fog-elimination system and discharged by a chimney to the atmosphere. The palm oil and water thus applied collect in the sump at the base of the mill and are run off to a palm-oil recovery system. The palm oil is separated here, and reclaimed, whilst the water, with a certain amount of palm oil in emulsion, is cooled and recirculated.

Inter-stand tensiometers indicate inter-stand tension and during acceleration and retardation the

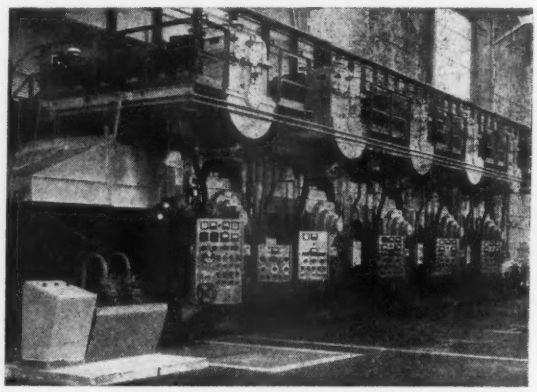

Fig. 18—View from the exit end of the 5-stand mill

tension is automatically varied. Off-gauge material is thus reduced to a minimum. Flying micrometers, which are located between stands 1 and 2 and after stand 5, register to 0·001 in.

After emerging from No. 5 stand the leading end of the strip is automatically engaged on the reeler by a belt wrapper and is recoiled into a 30,000-lb. coil. By this process 10 men can produce 500 tons of strip in an 8-hr. shift, or 750 tons in 12 hr., compared with the 6 tons (13,000 lb.) produced by the hand mill in the same time.

Electrolytic Cleaning

After the cold reduction, all traces of palm oil have to be removed from the strip. If this were not done, the oil would carbonize during annealing and would interfere with the subsequent tinning operation. The electrolytic cleaning lines are each capable of a maximum strip speed of 2000 ft./min. (Figs. 19 (folder) and 20).

The coils are loaded on to a conveyor ramp or on to the coil-charging car at the entry end of the line. They are pushed on to a mandril-type pay-off reel from which the strip is unwound ; the leading end is welded on to the trailing end of the preceding coil, so that the operation should be continuous.

The strip then passes through a continuous detergent cleaning unit, in which the main cleaning tank is electrolytic with grids above and below the strip and contains hot caustic solution. Beyond it is a second scrubber, a hot-rinse tank, a steam-heated drying unit, tension rolls, shears, and a recoiler. The coils are wound to 54 in. dia. (about 15,000 lb.) and are conveyed by tractor to the annealing bay.

Annealing

To obtain a ductile plate, it is necessary to repair the grain structure and to relieve the stresses set up in the cold-reduction process. This is achieved by heat-treatment in batch-type annealing furnaces (Figs. 21–23).

The annealing equipment consists of bases and furnaces, each base having two rows of four pedestals on which the coils are stacked four-high with the axes vertical, making a total of approximately 200 tons per charge. Over each stack is placed a special heat-resisting steel inner cover, the bottom being sealed with sand. A furnace is then placed over the complete charge.

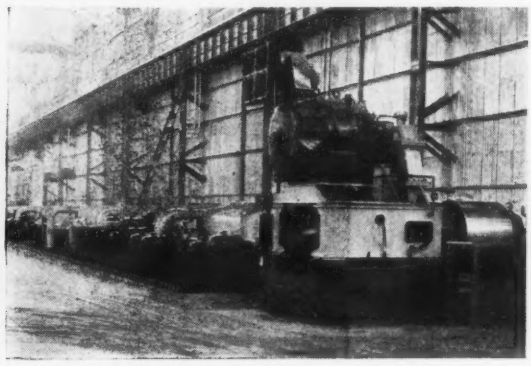

Fig. 20—View at the entry end of the electrolytic cleaning line

Each furnace is direct oil-fired from 30 burners, the flame being directed down and around the inner covers, which enclose the eight stacks. The temperature of each stack and the furnace itself is continually recorded and automatically controlled. During the heating and soaking cycle inert nitrogen gas (known as *N.X.*) is circulated by centrifugal fans in the inner covers and around the coils to prevent oxidation.

At the end of the soaking period the furnace is removed, and the inner covers are taken off when the coil temperature falls below the oxidizing range.

The coils are then taken off the pedestal, and when they are completely cool they are conveyed to the next department for temper rolling.

Temper Rolling

The 2-stand 4-high tandem temper mill is illustrated in Figs. 24 and 25.

It gives all coils a skin pass, the amount of cold work given depending on the purpose for which the plate is intended. For deep-drawing material the temper rolling is sufficient to give only a closed surface for tinning. For can-body stock the first pair of rolls is sand-blasted.

The maximum speed of the mill is 4000 ft./min., each stand being powered by a 1000-h.p. motor. The back-up rolls are 53 in. dia. × 47 in. wide and are of cast steel, whilst the forged-steel work rolls are 18 in. dia. × 48 in. wide. No strip coolant or lubricant is used. In rolling, the strip passes round a pair of 20-in. dia. top- and bottom-entry tension rolls, driven respectively by 500 and 250-h.p. motors, into No. 1 stand. From here it passes over another tension roll into No. 2 stand, which is identical with No. 1. On leaving No. 2 stand, the strip passes round a set of exit tension rolls, from where it is automatically engaged on a recoiling mandril. At this point the maximum weight of the coil is 15,000 lb. and it is approximately 54 in. dia.

When recoiling is complete, the coil is stripped off the mandril ; and at this stage the coil is destined to be either electrolytically or hot-dip tinned. If the former, the strip is passed through a preparatory line where the edges are side trimmed and the strip is recoiled, to ensure a good condition to maintain continuous operation in the subsequent tinning process.

If the strip is to be hot-dipped, it is side trimmed and cut to plate size in the shearing line, where, instead of coiling, the off-gauge is separated into one pile and the primes into another.

Preparatory Line

The preparatory line, shown in Fig. 26, is capable of handling and recoiling 30,000-lb. coils, up to a maximum width of 38 in., at a maximum speed of 1800 ft./min. Down-cut shears and a strip welder are incorporated so that coils can be built up to the maximum diameter desired. The speed of the strip through the line is controlled and adjusted by photo-electric cells located in the looping pits.

Shearing Line

The coils are fed to the shearing line, illustrated in

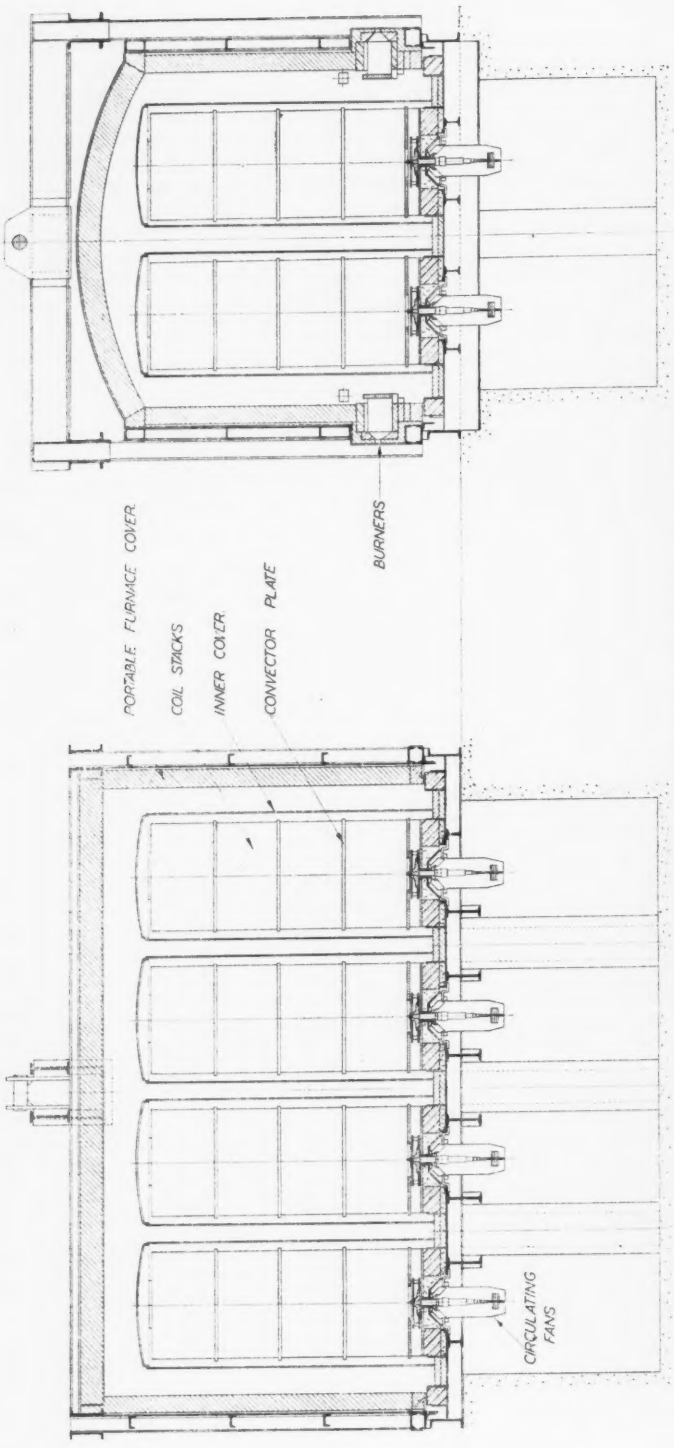

Fig. 21—Cross-section of portable-cover, open-flame annealing furnaces

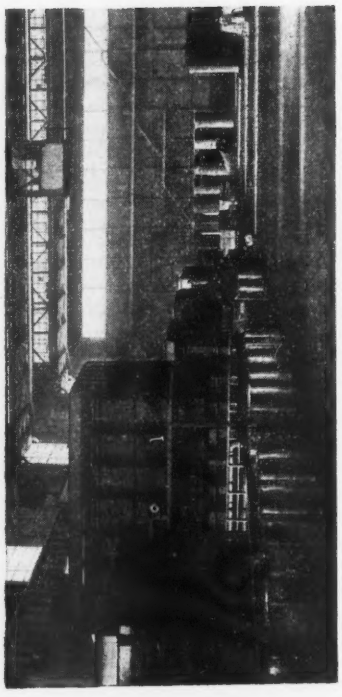

Fig. 23—Portable cover being lifted from annealing furnace

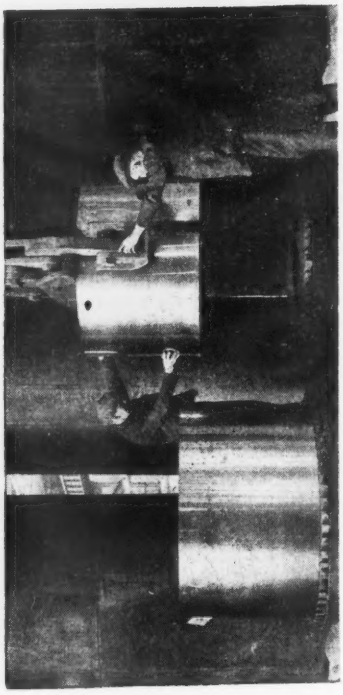

Fig. 22—Coils being stacked in the annealing furnace

Fig. 23—Portable cover being lifted from annealing furnace

Fig. 22—Coils being stacked in the annealing furnace

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OPERATIONS IN THE MANUFACTURE OF TINPLATE

as described in Period II

[Leighton Davies

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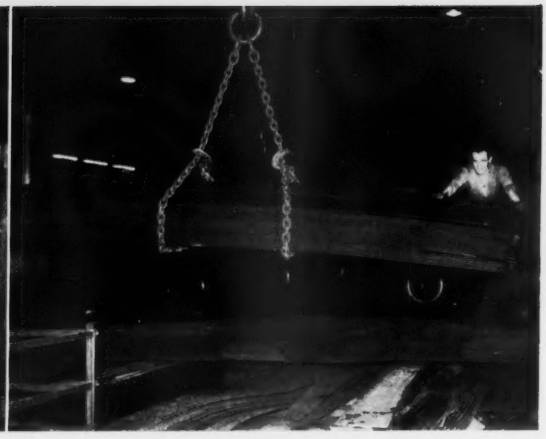
Discharging bars from truck from steelworks



Stacking bars to stock

Typical view of Welsh double mill

Cutting bars to size for rolling

Charging bars to furnace for rolling

Rolling iron

Rolling singles

Doubling singles

Recharging singles into furnace

Rolling doubles

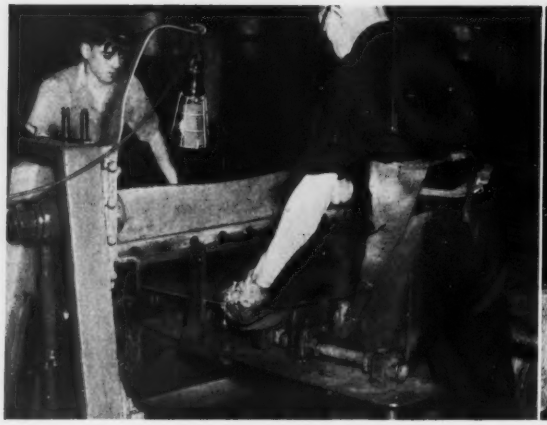
Doubling doubles

Opening doubles

Rolling and opening fours

Rolling and measuring eights

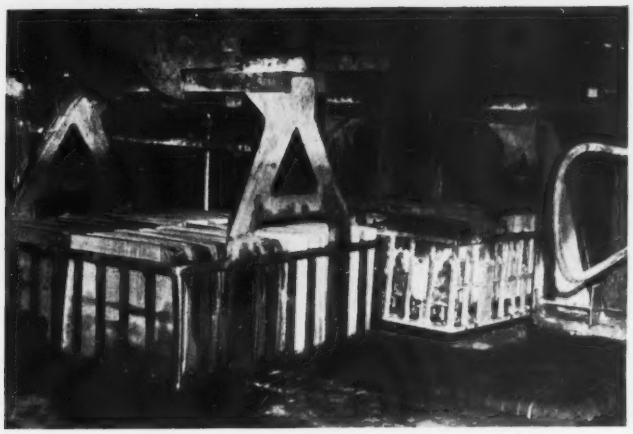
Placing rolled eights in packs



Shearing to front gauge

Shearing to back gauge

Opening



Black pickling ; charging cradle to vat

View of black-pickling machine ; exit end, showing packing benches for pickled plates

Pickled plates packed on stand for annealing

Annealing furnace and pots of annealed work

Assorting bay, showing stock of plates for cold rolling and view of entry end of cold rolls

Plates being cold rolled

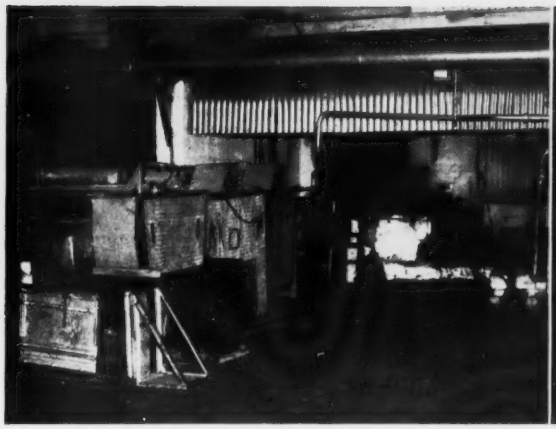
View of finishing end of cold rolls, showing white packing of plates after cold rolling

View of white pickling after white annealing

View of hot-dip hand tinning operation

View of hot-dip hand tinning operation, showing plates entering and leaving greasepot

Plates coming out of greasepot (side elevation) into cleaner

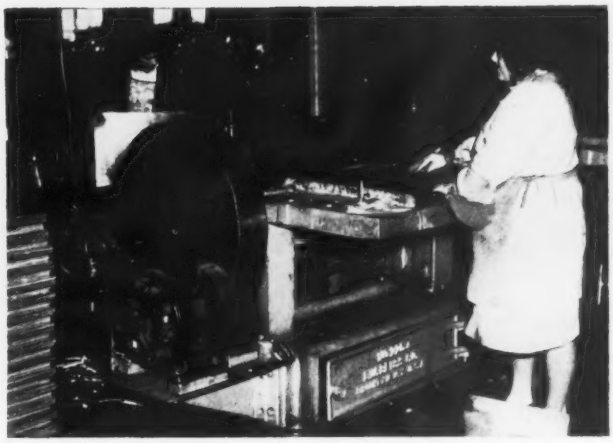


View of cleaning machine with tinpot in background

Re-dusting after tinning

Assorting and reckoning

Piling after reckoning



Slitting tinplates for oil-can and other purposes

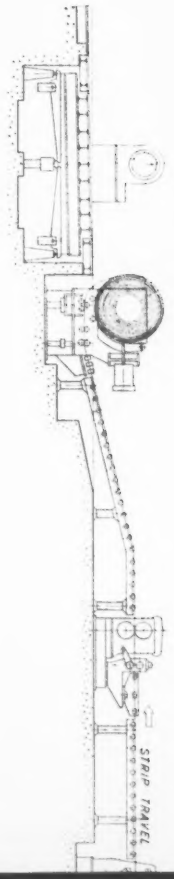
Packing into cardboard containers

Tinplates for export in steel packs

Method of loading and bracing bulk-packed tinplate for despatch in railway wagons

Tinplate in cardboard containers for home and export

Leighton Davies]



EXIT RAMP

SCALE

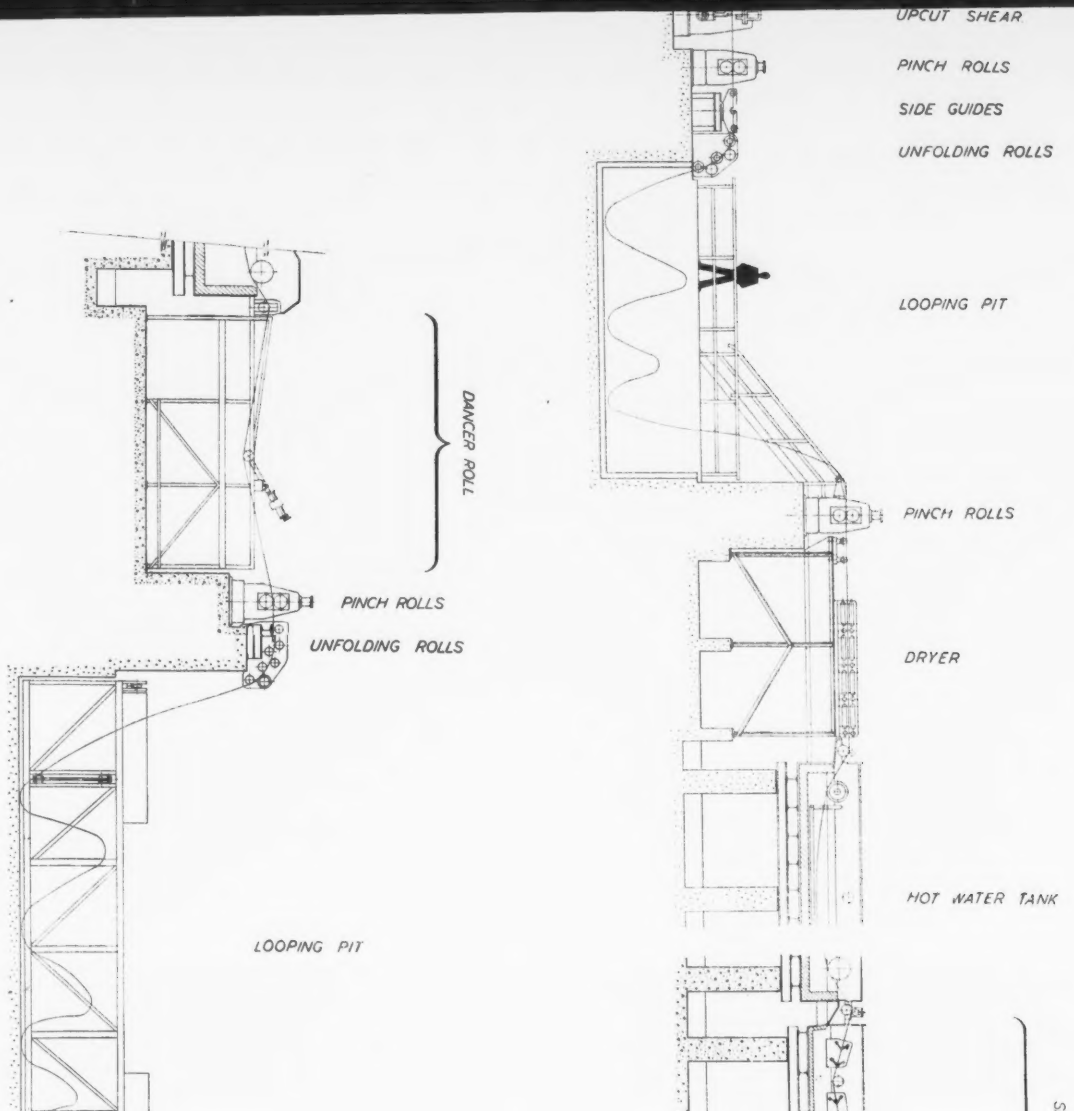
UPCOILER

CONVEYOR

SIDE TRIMMER

SIDE GUIDES

CONVEYOR


UPCUT SHEAR
PINCH ROLLS
SIDE GUIDES
UNFOLDING ROLLS
LOOPING PIT
PINCH ROLLS
DRYER
HOT WATER TANK
DANCER ROLL
PINCH ROLLS
UNFOLDING ROLLS
LOOPING PIT

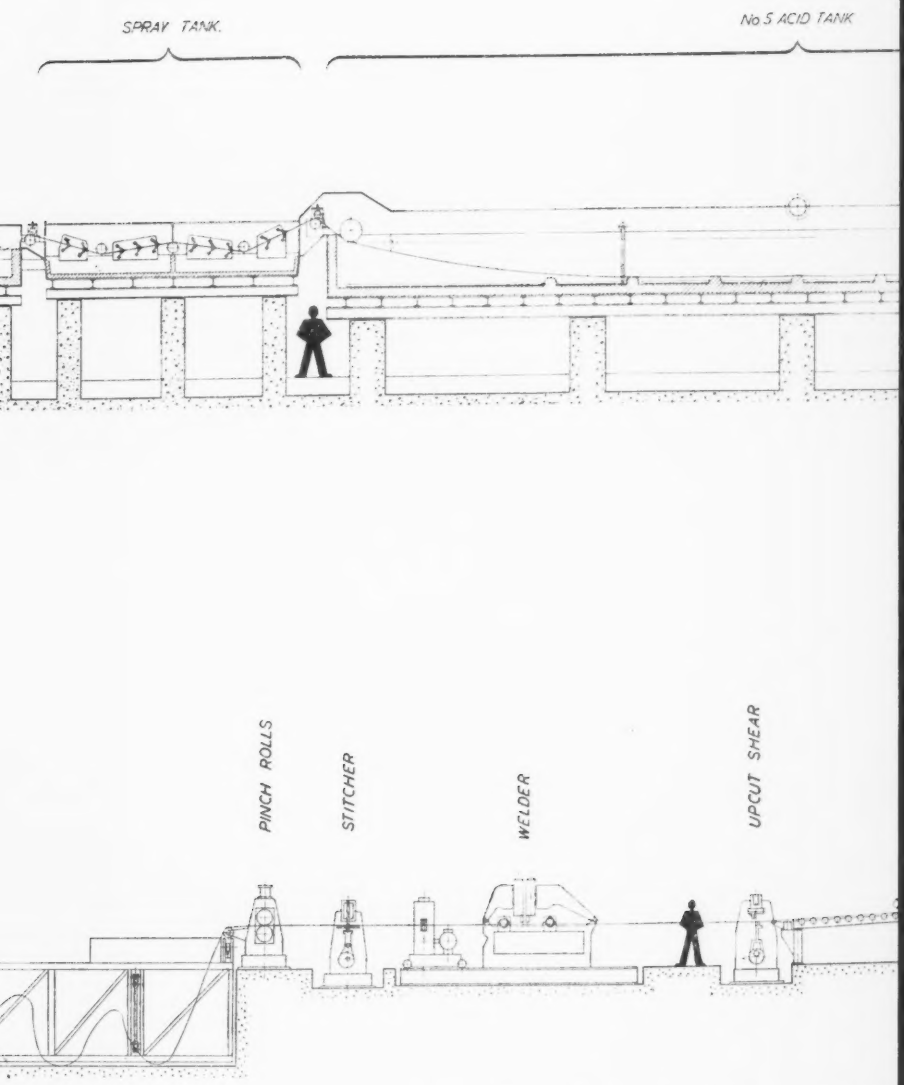


Fig. 15—Diagram of the continuous pickling line

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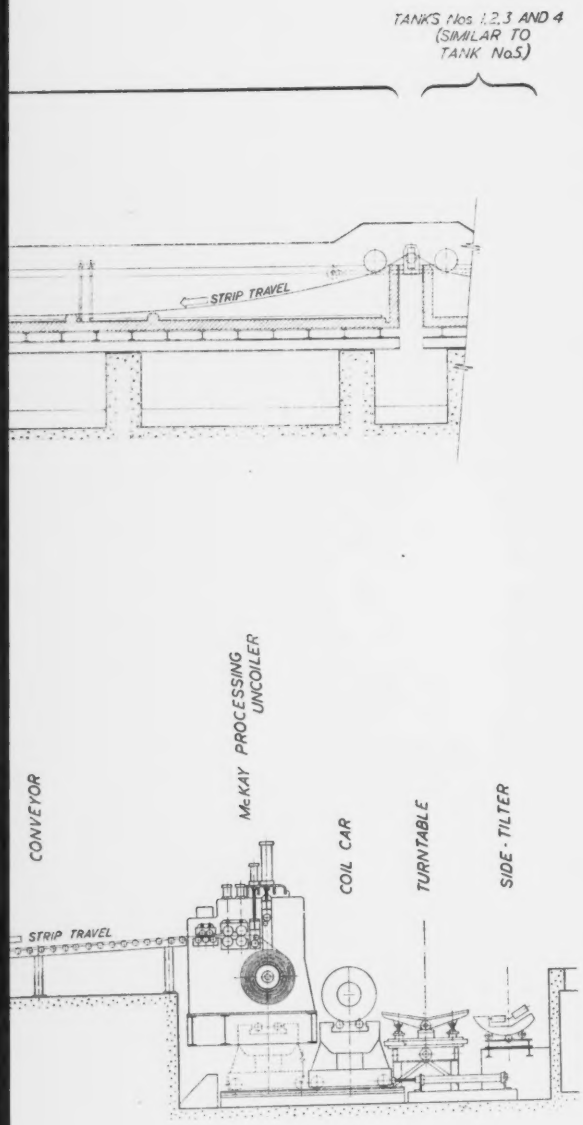
FIG. 15



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XUM

XUM

BELT WRAPPER
REEL AND STRIPPER CARRIAGE
REEL ENTRY APRON
UPCUT SHEAR
TENSION ROLL UNIT
LOOPING PIT
PINCH ROLLS
RE-THREADER DRIVE
HOT AIR DR

XUM

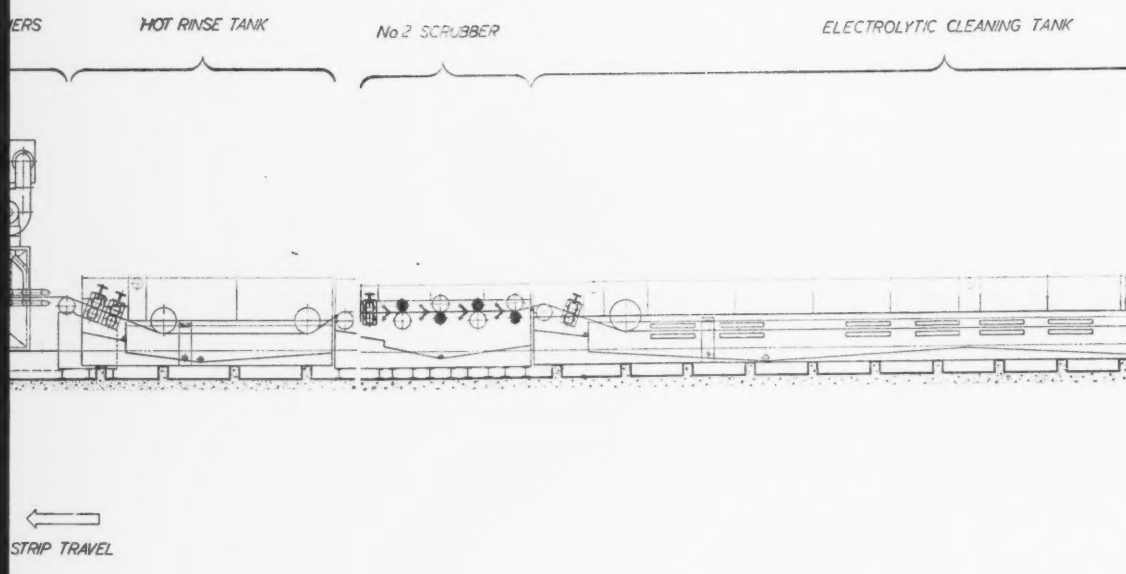

Fig. 19—Diagram of the electrolytic cleaning

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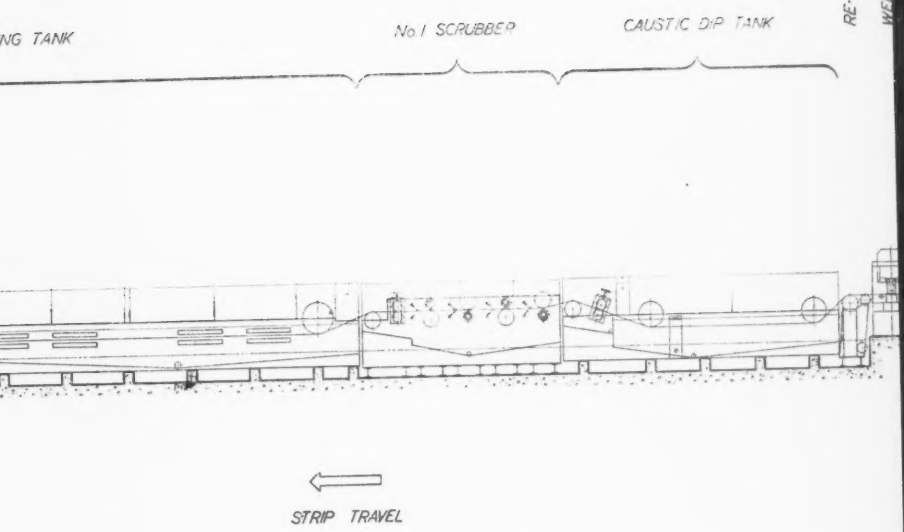

lytic cleaning line

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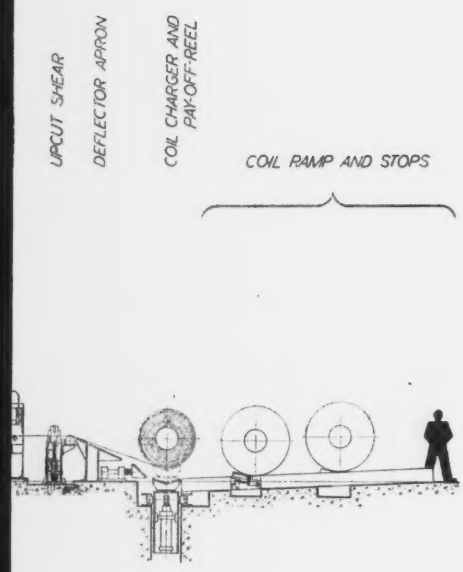
FIG. 19



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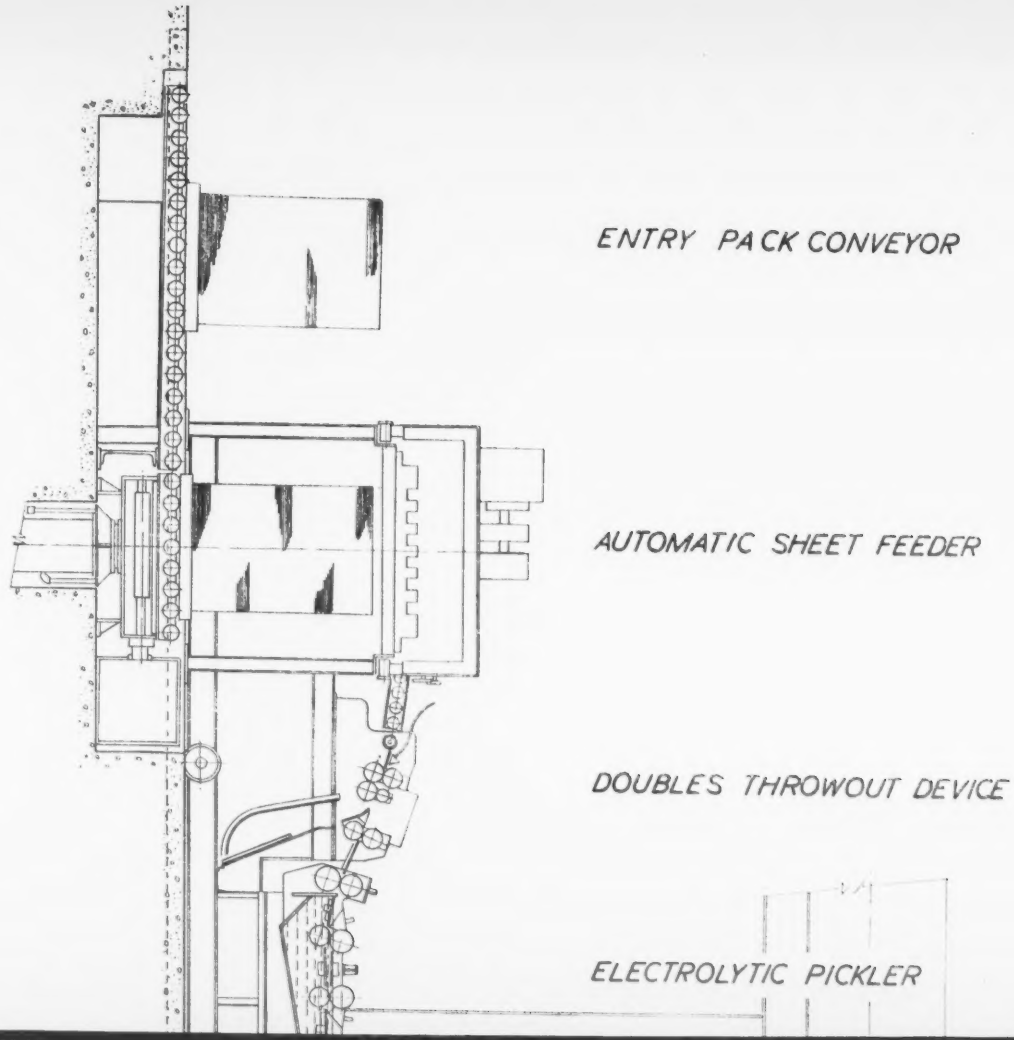
ENTRY PACK CONVEYOR
AUTOMATIC SHEET FEEDER
DOUBLES THROWOUT DEVICE
ELECTROLYTIC PICKLER

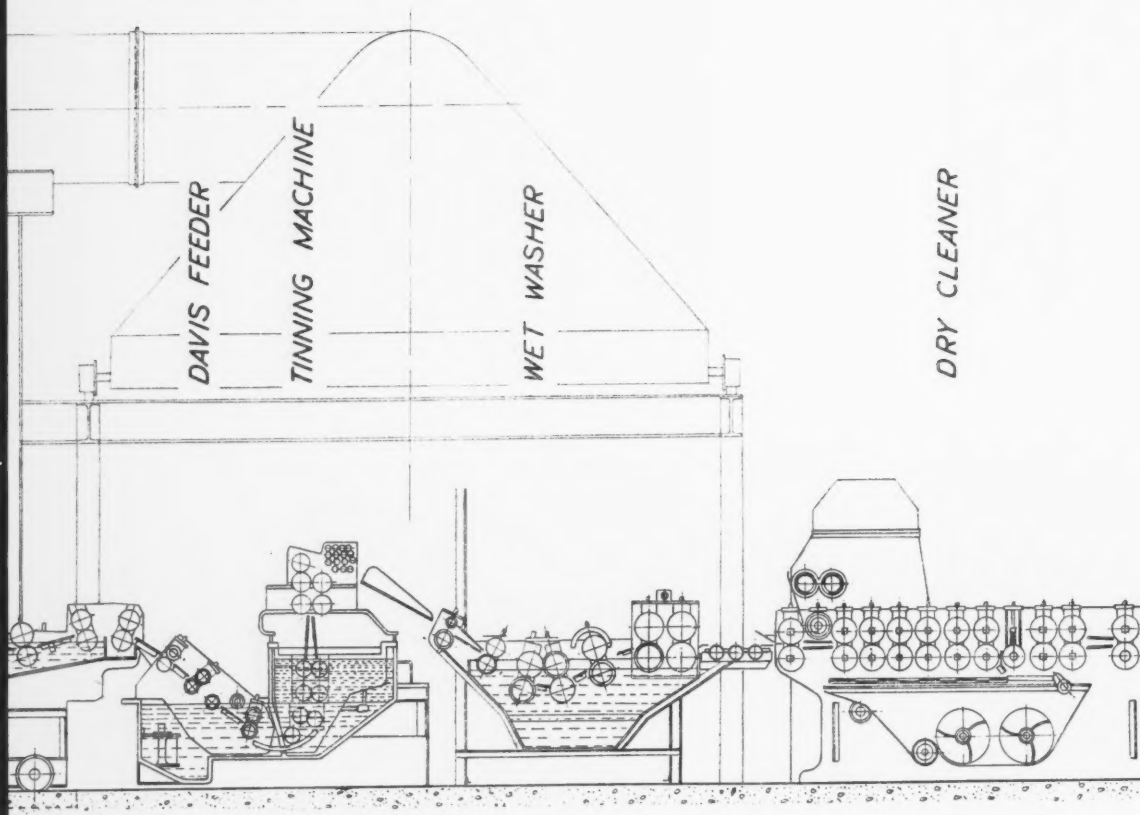

Fig. 31—Cross-section of the hot-dip tinning machine with inspection line attached

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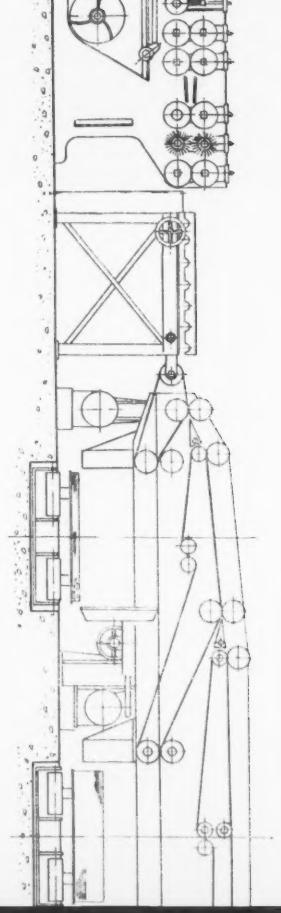


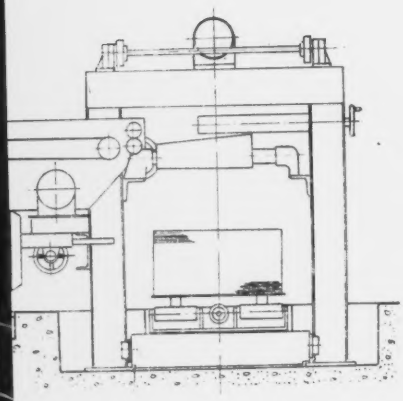
CONVEYOR

WASTE-WASTE PILER

MENDERS PILER

FIG. 31

PRIME PILER



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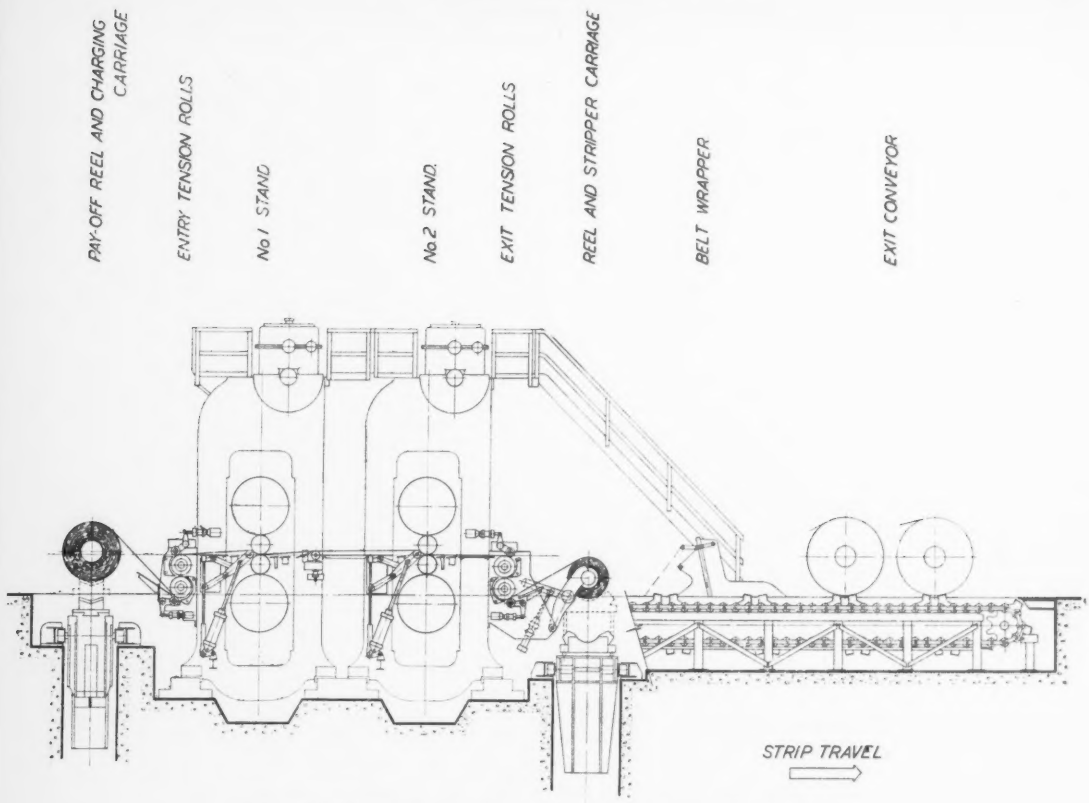

Fig. 24—Diagram of 4-high, 2-stand tandem temper mill

Figs. 27 and 28, through a looping pit into the side trimmer. The looping pit is equipped with photo-electric cells to ensure speed control between the pay-off reel and the rotary side trimmer. The trimmed strip then passes through a second looping pit, similarly controlled to prevent tension, and on through mechanical off-gauge and pin-hole detectors. From this stage it passes through roller levelling operations, before being cut up into sheets by Hallden-type rotary-driven shears. The maximum speed of the shearing line is determined by the length of the cut and varies from 650 ft./min. at 18 in. to 1000 ft./min. on the 37½-in. cut.

The sheared plates then travel along a conveyor to a classifier, where the off-gauge and perforated sheets are automatically stacked in one pile and the primes in another. The prime plates are then taken on stillages to the hot-dip tinning section.

Electrolytic Tinning

Electrolytic tinning of strip can be carried out by two main methods, one acid and the other alkali. In both methods, the strip forms the cathode while slabs or strips of tin form the dissolving anode. In the acid method the electrolyte is made up of a solution of stannous sulphate, cresol-sulphonic-acid, free sulphuric acid, gelatin, and beta-naphthol. In the alkali method, the electrolyte is a solution of sodium stannate containing small quantities of free caustic soda, sodium acetate, and hydrogen peroxide. In both these methods the amount of tin deposited is controlled by one or more of the following factors: the size of the anode; the ratio of the surface areas of cathode and anode; the distance between cathode and anode; the rate of travel of the strip; the density of the bath; and the electric current.

Ferrostan Tinning Line

At Trostre the electrolytic tinning is of the acid ferrostan type. The unit, shown in Figs. 29 and 30,

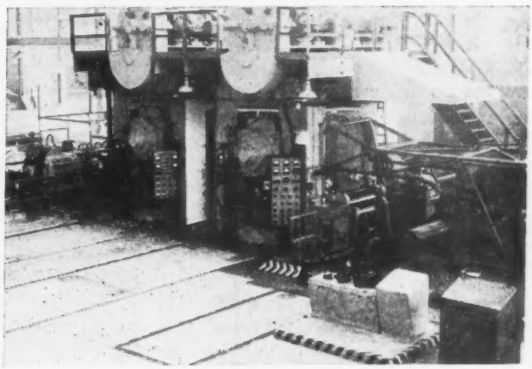

Fig. 25—View from the exit end of the 2-stand mill

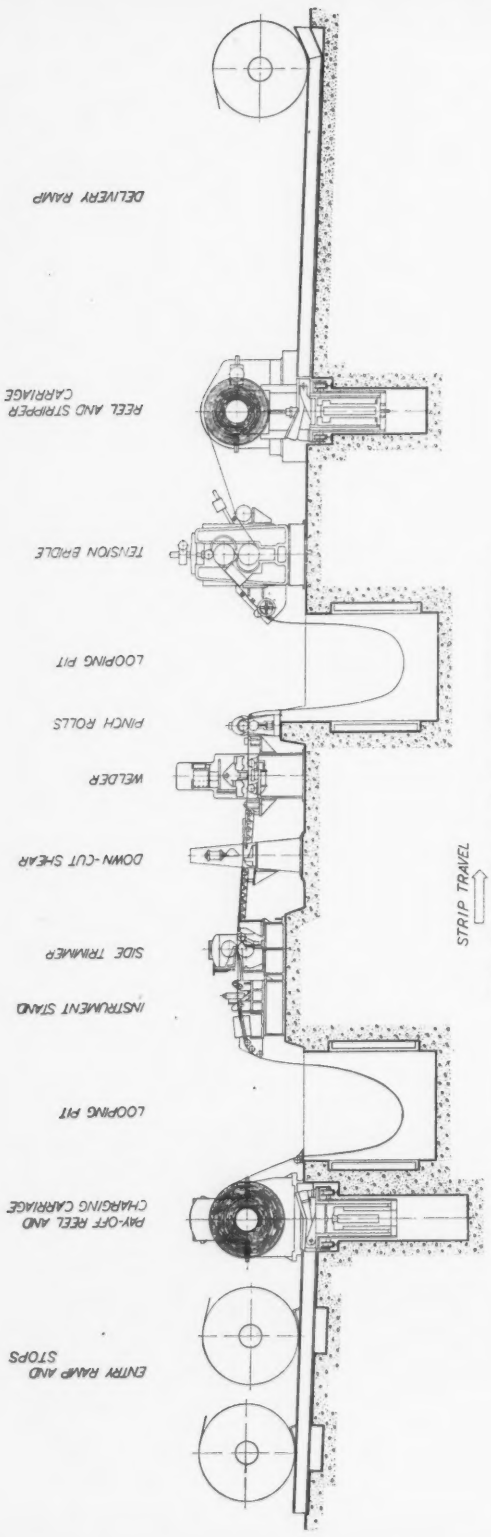

Fig. 26—Diagram of the coil preparatory line

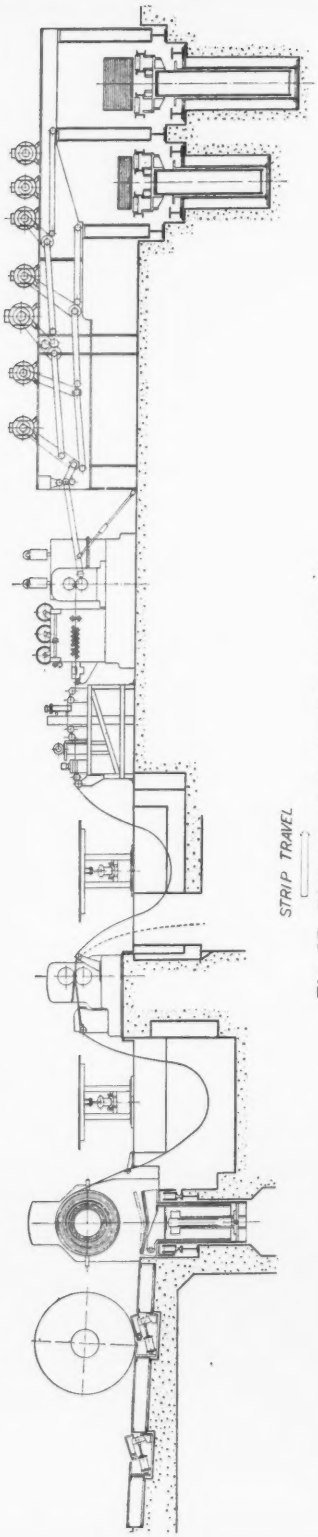

Fig. 27—Diagram of the tinplate shearing line

is designed to work continuously and to handle coils weighing 30,000 lb. at a maximum width of 38 in. It will deposit a tin coating of ½ lb. per basis box at a speed of 800 ft./min., but with correspondingly decreased speed for heavier coatings. Selenium rectifiers supply the necessary direct current up to a maximum of 60,000 amps. at 16 V. The amperage varies with the speed of the line and the weight of coating being deposited, and is automatically controlled to give a constant weight of coating at constant speed.

There are two uncoilers to aid continuous operation. The leading end of the coil is sheared and welded to the trailing end of the preceding coil, time for this operation being provided by two loops held in a 70-ft. deep pit. The length of the strip in the loop is controlled by photoelectric cells fixed near the bottom of the pit. The strip then passes through pin-hole and off-gauge detectors, for automatic rejection at the exit end of the line, followed by cleaning, which consists of electrolytic degreasing, cold-water rinsing, electrolytic pickling, and, finally, spraying with water and brushing.

The next operation is tinning, which comprises five plating tanks and one drag-out tank, where the strip is washed and the electrolyte is recovered for future use. The strip then enters the flow-melt unit, where it is electrically heated to allow the tin on the surface of the strip to flow evenly; this gives it a bright appearance and also improves the quality. It is then sprayed with chromic acid to prevent staining during storage and to enhance corrosion resistance. After drying, the strip is coated with a very thin film of cotton-seed oil, which affords the necessary lubrication for subsequent fabricating operations. It is then classified in a manner similar to that described in the shearing line, except that the classification is controlled from two visual inspection positions. The strip is sheared into plates of the required width and directed into one of three piles. Any off-gauge or perforated plate that has been detected by a flying micrometer and pin-hole detector situated further back in the line is deposited in the first pile. The second pile contains any plate of doubtful appearance, and the third contains the prime plate, which is automatically counted and recorded by means of an electric-eye counter. Stillages from the first and second piles are re-assorted for recovery or retreatment, whilst those from the third pile are bulk-packed for shipment.

Fig. 28—View of the tinplate shearing line

Hot-Dip Tinning

Plates from the shearing line, already cut to finished size, are hot dipped in a mechanized version of a 2-path Poole Davis tinning pot, in which the tin is heated by thermostatically controlled electric immersion heaters. In this unit (Fig. 31 (folder)) the actual tinning operation is preceded by an automatic feeder and hydrochloric acid electrolytic pickler and washer.

After cleaning in an Aetna-type cleaning machine sheets are delivered simultaneously from each path to a cross conveyor. This conveyor transfers the sheets one behind the other to the inspection line, the travel of which is parallel to the tinpot pass line. At this point an inspector checks every sheet for gauge and quality and classifies them into three categories. By means of push-button electrically controlled deflector gates along the classification line the inspector directs the prime plates into a pile at the end of the classifying table, where they are automatically counted and recorded, and stacked in piles of a known number ready for packing. The second pile consists of menders and the third of defective plates. The menders from both electrolytic and hot-dip tinning lines are retinned in the hot-dip tinning unit.

The types of waster that are produced by the strip method of production are far less than those obtained in the hand mill and, of course, the amount of manhandling is very small. Thus, in the old-type mill it took 7000 men to produce 7000 tons of plate per week; in the modern mill only 1000 men are needed to produce 10,000 tons per week.

This progress has introduced a sociological problem, but the manufacturers have anticipated its effects by creating a fund to mitigate against possible unemployment. This has been done by making a levy on the products of the mills over the past few years, which will result in a total sum of about £500,000 before the plant at Trostre is in full operation.

FUTURE DEVELOPMENTS

In very early times tinplate was used mainly as a building material, or for open vessels and ornaments. But with the advent of canning for the preservation and storage of foodstuffs and other perishable materials, it found its real use. In the many years during which tinplates have been manufactured, only in the last 50 have there been the most radical changes in methods.

At the outbreak of war, in 1939, rolling in strip form had become almost universal in the U.S.A., and one hot-and-cold strip mill plant was in production at Ebbw Vale, in South Wales. Various countries on the Continent were also developing along the same lines. Before that time most of the plates exported from the U.K. (about 400,000 tons per annum) were hot-mill rolled, but by an economic arrangement with the U.S.A., our foreign buyers, especially South America, took their supplies from America in the form of cold-rolled plates. The foreign can-makers therefore adjusted their plants to suit this type of plate and acquired a preference for its better stamping

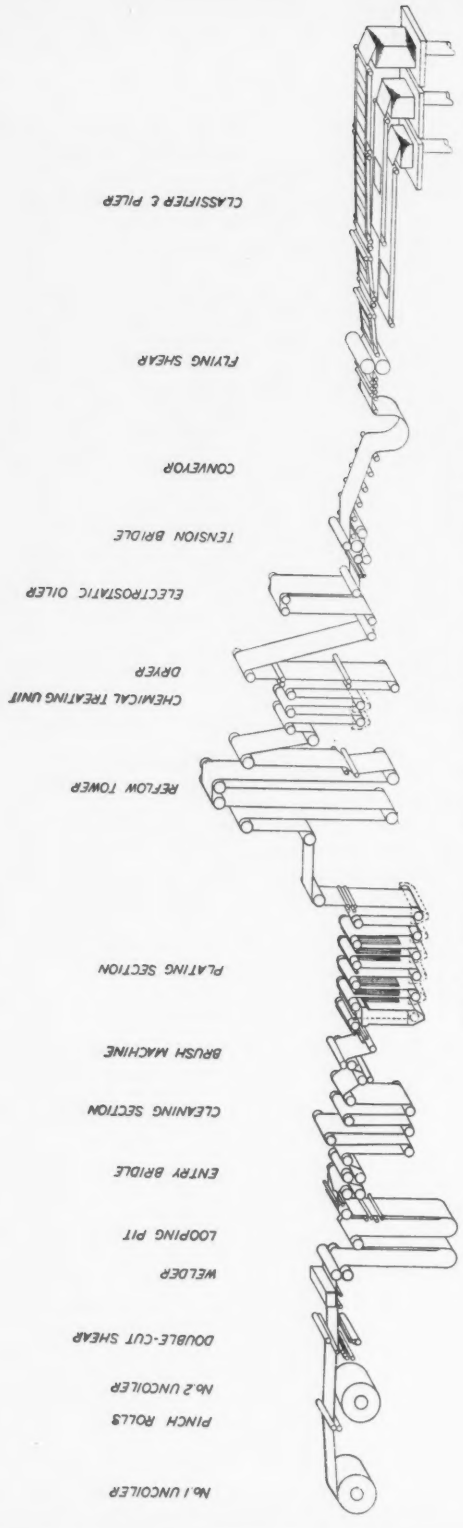

Fig. 29—Schematic diagram of the electrolytic tinning line

qualities. Hence, to be able to compete in export trade with America it became imperative that strip rolling should quickly supersede the old pack method in this country.

In 1947, therefore, the erection of the second cold-reduction plant was started at Trostre, in Llanelly, by the Steel Company of Wales, Ltd., the hot mill for supplying the coil being built at Port Talbot. This is likely to be followed by a third cold-reduction plant and also by the reconditioning of the original plant at Ebbw Vale to produce a greater output. It is anticipated that these three plants will produce sufficient tinplate to cope with the total future demand, both for home consumption and for export, of between 20 and 25 million boxes per annum; that is, about one sixth of the present world production.

While these developments have been taking place, further experiments in still more modern methods of production have continued, especially in America. The following items are among those that are being, or will be, investigated:

(1) Continuous casting of strip in tinplate gauges.
(2) Powder rolling of strip in tinplate gauges.
(3) Mechanical descaling instead of wet pickling.
(4) Development of cluster and planetary mills.
(5) Development of the 5-stand cold-reduction mill as a continuous unit, with welder, looping pits, or towers at either end, and shear and recoiler at the exit end. (Thus requiring lower-powered motors with lower speeds for equivalent outputs.)
(6) Possibility of higher working speeds.
(7) Coupling of two or more of the present continuous operations.
(8) Abolition of cleaning by wet detergents and its replacement by a combination of a cleaning operation with the annealing treatment preceding continuous annealing.
(9) Continuous annealing by either the horizontal or the vertical method, preceded by electrolytic cleaning to take the place of the present separate cleaning unit with batch annealing.
(10) Production of strip with 'universal' temper by continuous annealing.
(11) Continuous hot-dip tinning of wide strip, covering coatings from $\frac{1}{4}$ to 2 lb. per box.
(12) Sale of tinplate (both electrolytic and hot-dip) in coil form direct to consumers.
(13) Use of very lightly coated electrolytic plate (0·2 lb.) instead of blackplate. (Thus eliminating finger marking and rusting, and also facilitating soldering.)
(14) Production and use of differential coatings on electrolytic tinplate, whereby a heavier coating of tin is deposited on one side, or with tin coating on one side only, with a consequent saving of tin.
(15) Effect of atomic energy.

It must be remembered that, as tin has always been a most expensive commodity, it has been the aim to cover plates with as thin a coating as possible, and yet to produce a smooth and non-porous surface. To obtain this surface the tinning operation and tinning machinery have gradually been perfected, as

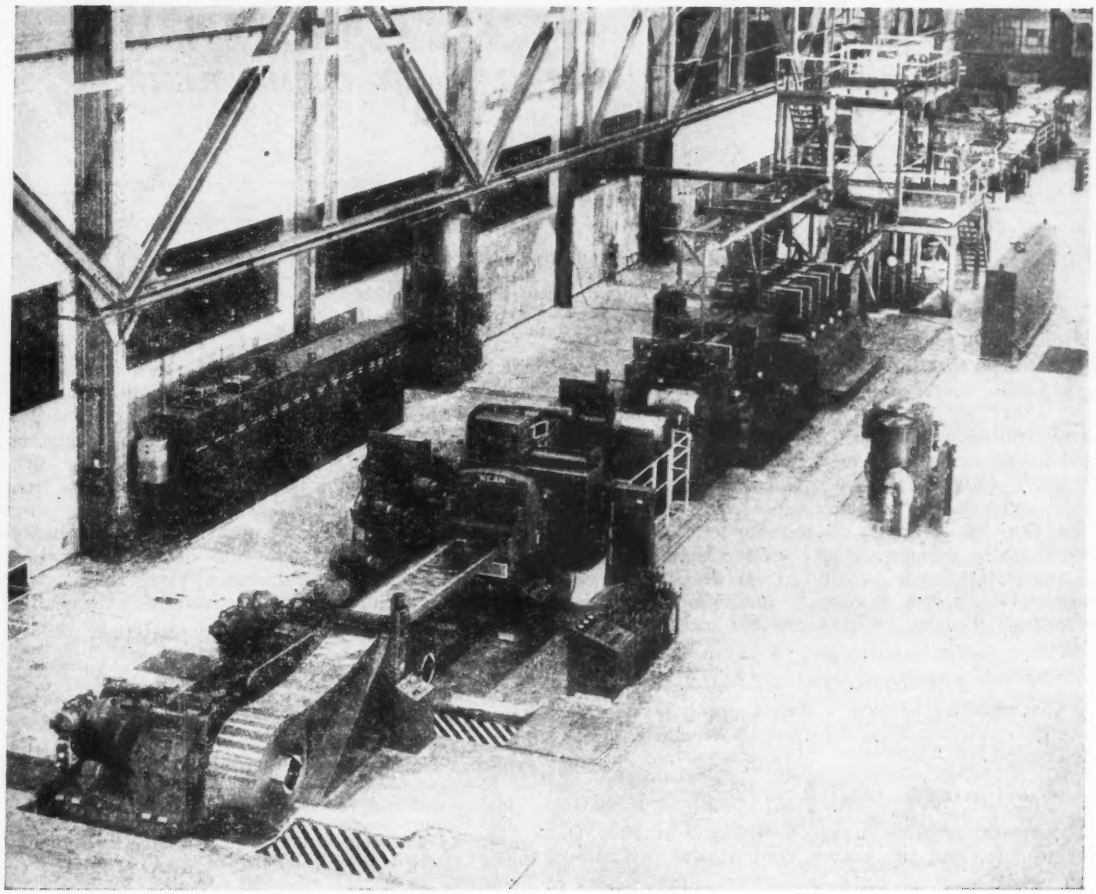

Fig. 30—General view of the electrolytic tinning line

is shown by the weight of tin coatings recorded over the past years :

Year	Weight per basis box, lb.*	Year	Weight per basic box, lb.*
1755	14	1900	$2\frac{1}{2}$
1820	10	1912	$1\frac{1}{2}$
1857	9	1940	1
1874	$4\frac{1}{2}$	1952	$\frac{1}{4}$ (electrolytic)

* One basis box is 112 sheets of 20 in. × 14 in. (31,360 superficial inches), weighing 108 lb.

There are signs that the tinplate industry will, in the future, be faced with competition from substitute materials, such as glass, cardboard, aluminium, and aluminium-coated steel, in fields where tinplate has, so far, been supreme. Nevertheless, the future tinplate manufacturers will be aware of this competition, and one is confident that, being of the same calibre as their ancestors, they will make such progress as will enable them to meet and overcome it.

In concluding his address the President remarked :

The developments in the manufacture of tinplate over the years have been remarkable, and I think we must pay tribute to the technicians, engineers, and metallurgists who have been responsible for this magnificent work, and also pay due homage to those early pioneers who made our industry. The hardest struggle is always in the beginning. We live to benefit from other peoples' experiences, and we live to learn and improve.

I acknowledge my indebtedness to Mr. C. H. Cunniffe, Mr. G. A. Johns, and, in particular, to Mr. J. Shirley Gazard, for the valuable assistance they have given me in preparing this Address. I am also very grateful to many of the staff and workpeople with whom I have come in contact in the industry during my lifetime and who have given help and guidance in my early days, and whose loyalty and co-operation helped to make my work fascinating and interesting in spite of its onerous character.

I sincerely trust that the Country will maintain its traditional position in the forefront of this particular industry—" The Tinplate Industry."

Volume Change at the Ar_3 Transformation

By A. H. Smith, M.Sc., and F. C. Thompson, D.Met., F.I.M.

SYNOPSIS

In view of the great discrepancies between the results obtained by earlier workers, the volume change associated with the $\gamma \rightarrow \alpha$ transformation has been redetermined for a specially pure Armco iron, and has been found to be 1·16%. This figure is in good agreement with that derived from X-ray data.

Since this value should be about 9% if the iron ion is the same size in both the γ and α forms, a significant change in ion size must occur, as is expected from the alteration in co-ordination number. It has been found that this change amounts to a contraction of 2·4% of the ionic radius at the Ar_3 inversion, which agrees well with Goldschmidt's figures.

ASSUMING that the ion is of the same size in the two forms, there should be a change of volume of about 9% at the Ar_3 inversion from face- to body-centred cubic iron. Although measurements of the linear change at the Ar_3 point vary greatly, from 0·082%[1] to 0·38%,[2] they are all very much less than 3%, and a redetermination appeared to be justified. The use of an ordinary dilatometer for the measurement of the volume change assumes that the linear dimensions change equally in all directions; this assumption is not necessarily justified, and it was therefore decided to measure the actual volume change.

EXPERIMENTAL DETAILS

The material employed was a specially selected sample of Armco iron, the analysis of which was as follows:

C, %	Si, %	Mn, %	S, %	P, %
0·02	0·005	0·02	0·03	0·005

The specimens were annealed *in vacuo* at 1000° C. before use, and the carbon content was estimated micrographically. Figure 1*a* shows the normal structure and Fig. 1*b* shows the structure typical of a few areas in which carbide was present at the boundaries. The freedom from 'veining' and inclusions suggests an oxygen content which is on the low side for such material. The real justification for using this iron is that the results obtained when using very pure forms of the metal are unsatisfactory, probably because of the very slow rate of transformation. Austin and Pierce,[3] for instance, state that "pure iron is not a suitable material for measuring the change in macroscopic linear dimensions in iron at the A_3 inversion, since the change is neither reversible nor predictable."

The measurements were carried out in the apparatus shown in Fig. 2. The sample of iron, approximately 2 in. long × 1 in. dia., was heated in molten tin in a cylindrical silica vessel in an atmosphere of hydrogen,

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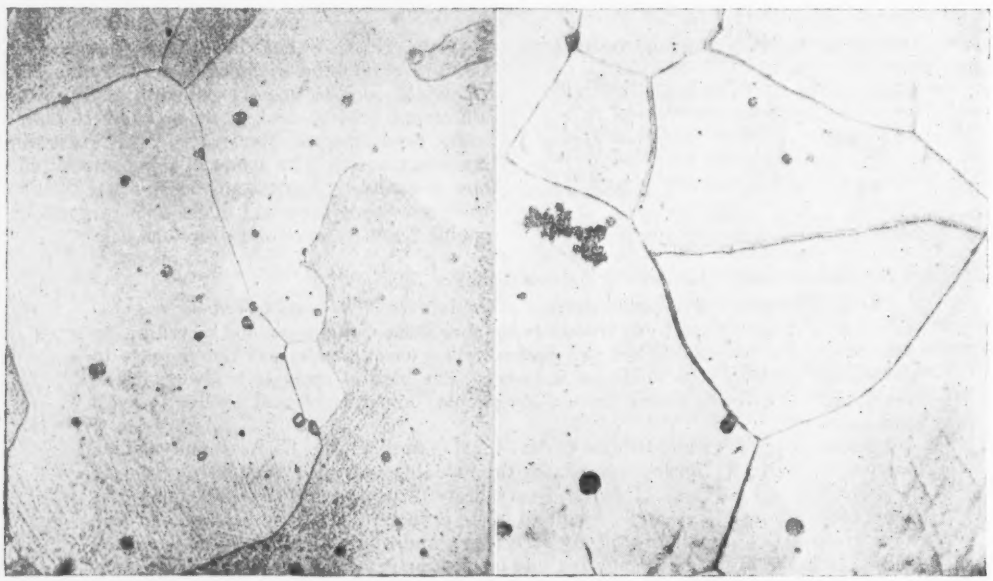
Dr. Thompson is Professor of Metallurgy at the University of Manchester; Mr. Smith is a research student in the Department of Metallurgy at the University.



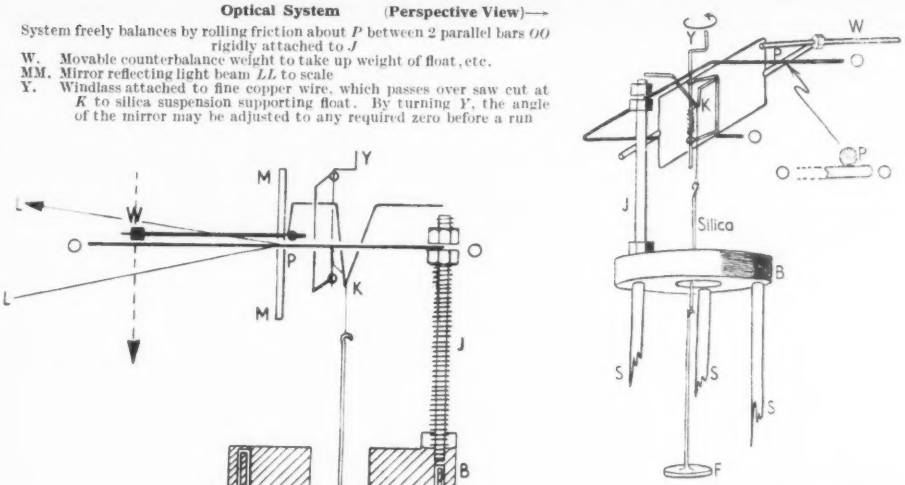
(*a*) (*b*)

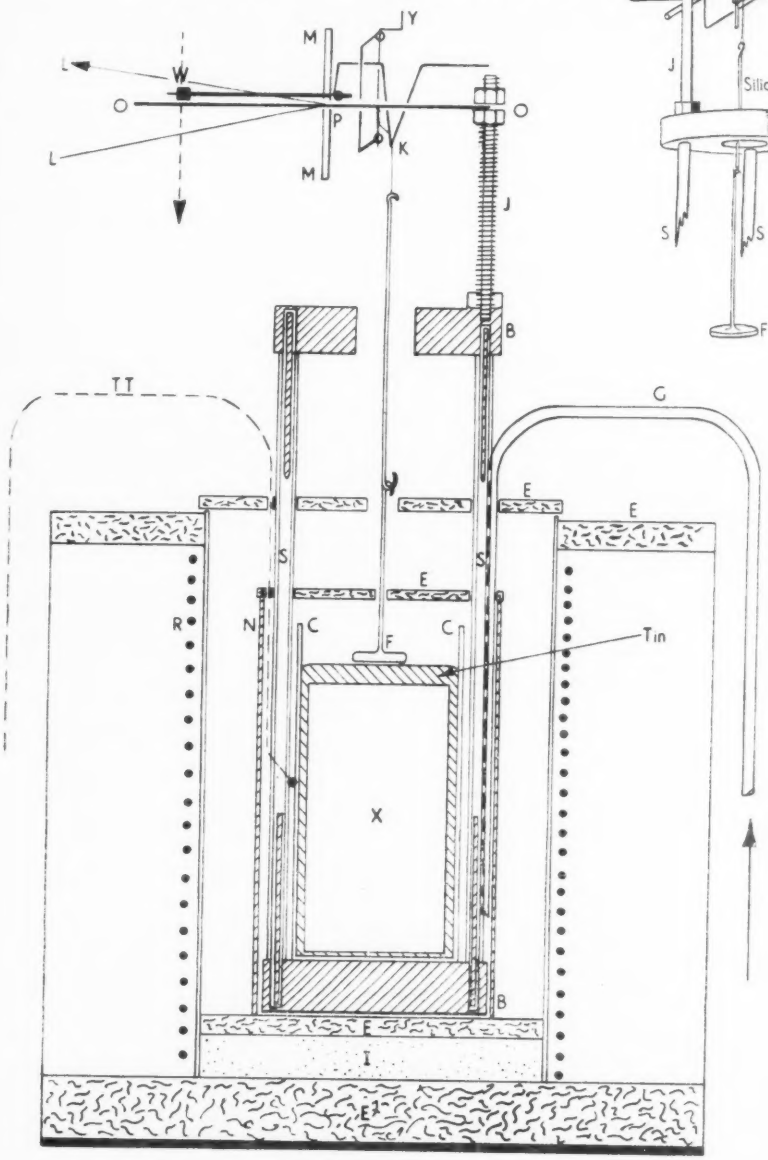
Fig. 1—Microstructures showing: (*a*) Carbonless area (normal); (*b*) boundary carbide × 700

Optical System (Perspective View)—→

System freely balances by rolling friction about *P* between 2 parallel bars *OO* rigidly attached to *J*

W. Movable counterbalance weight to take up weight of float, etc.
MM. Mirror reflecting light beam *LL* to scale
Y. Windlass attached to fine copper wire, which passes over saw cut at *K* to silica suspension supporting float. By turning *Y*, the angle of the mirror may be adjusted to any required zero before a run





Furnace and Specimen

R. Furnace windings
E. Asbestos sheet
I. Sand insulation for base
N. Reducing atmosphere container
G. Reducing gas feed pipe
BB. End rings, upper one perforated with central hole and kept at constant distance by three equilaterally spaced silica comparator rods *SS*
CC. Cylindrical silica crucible
X. Specimen, in tin bath
F. Silica float resting on tin meniscus transmitting rise and fall to optical system
J. 2 in. of O.B.A. brass rod supporting optical system

Fig. 2—Diagram of apparatus

and the movement of the tin meniscus was followed by means of a small, counterbalanced silica float attached to an optical lever system. By using a modified Saladin method, the meniscus–level/temperature curve could be plotted directly. The optical system was calibrated directly in the apparatus shown in Fig. 3. By means of the micrometer and the lever bar working at a mechanical disadvantage of 5 : 1, the deflection of the mirror, corresponding to any movement of the float, could at once be determined.

The corrections for the expansion of the silica rods and of the supporting head of the mirror system were negligible, amounting at most to about 1% of the observed value. The changes in the level of the meniscus took place smoothly, and there was no evidence of sticking. The hydrogen atmosphere is not likely to have had much effect on the results, since the specimen was completely immersed in the tin; this conclusion is further confirmed by the fact that, when coal gas was substituted for hydrogen, no sign of carburization of the iron could be detected. However, to establish definitely that the hydrogen atmosphere had not given rise to error, a final experiment was

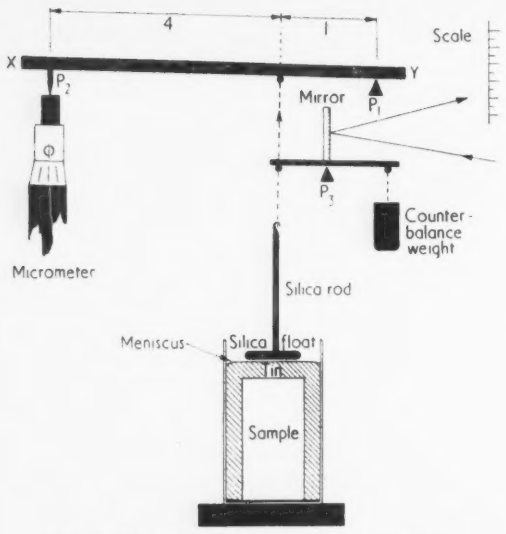


Fig. 3—Diagram of calibration apparatus

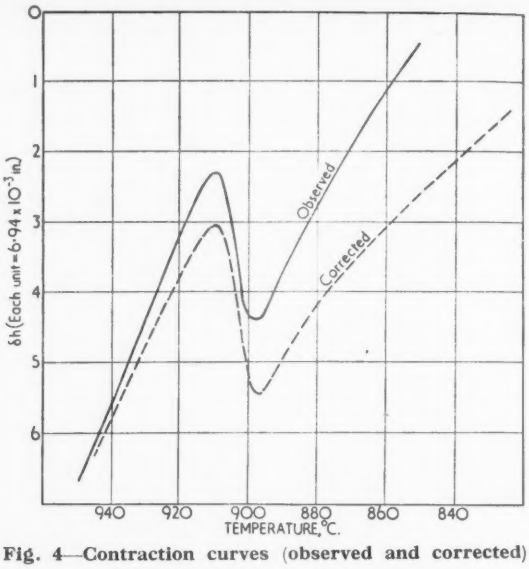


Fig. 4—Contraction curves (observed and corrected)

carried out *in vacuo*; this gave a result which was almost identical with the mean of the previous results.

Preliminary runs had been made with the sample immersed in lead, but difficulties arose owing to floating of the specimen and a rather serious attack on the silica vessel. When tin was used as the immersion liquid, its attack on the sample during the course of a run was insufficient to produce any serious error in the result, and the measured volume was affected by, at most, $1\frac{1}{4}\%$. From a consideration of the results of Bannister and Jones,[4] and since the specimens used in the present work were never at the maximum temperature of 950° C. for more than $\frac{1}{2}$ hr., the penetration of the tin should be of the order of 0·0025 in. To minimize any effect of this contamination, each run was carried out on a fresh specimen. Also, one sample was subsequently maintained at 950° C. for 5 hr. before carrying out the test, and the curve showed no marked divergence from normal.

The change of volume of the iron is the net result of the alteration in volume of (*a*) the sample, (*b*) the tin, and (*c*) the container. By carrying out a preliminary run with tin alone, corrections for (*b*) and (*c*) can be obtained.

An experimental curve for which the sample was slowly heated to 950° C., kept at that temperature for 15 min., and then cooled at a rate (through the transformation range) of 3° C./min., is shown in Fig. 4, together with the corrected curve. The vertical distance between the minimum and maximum in this corrected curve represents the movement of the meniscus during the transformation, and this movement is readily convertible into the corresponding change of volume, from the known dimensions of the crucible and sample.

In four runs, values of 1·24, 0·97, 1·26, and 1·17* were obtained for the percentage change of volume on passing from the γ to the α state, the mean being 1·16%. This corresponds to a linear change of 0·39%, which may be compared with the value 0·38% calculated from the X-ray data of Esser and Müller.[2]

Comparison of this value, 1·16%, with those of most earlier workers emphasizes the uncertainties that may arise in the determination of volumetric changes from experiments in which a linear dimension only is measured.

* *In vacuo.*

DISCUSSION

Comparison of the mean result (1·16%) with the value of 9% associated with no change of ionic volume, indicates that a marked decrease in the size of the iron ion must occur when face-centred γ transforms to body-centred α. This change is to be expected, owing to the alteration in the co-ordination number.

If r and r' are the ionic radii in the body-centred and face-centred cubic forms, and if x is the percentage change of volume associated with the transformation, then :

$$\frac{r'}{r} = 1{\cdot}029\left(1 + \frac{x}{100}\right)^{-\frac{1}{3}}$$

Substituting for x :

$$\frac{r'}{r} = 1{\cdot}024,$$

i.e., the ionic radius contracts by 2·4%.

This figure is identical with that of 1·26 : 1·23, *i.e.*, a contraction of 2·4%, given by Pauling[5] (after Goldschmidt).

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Microscopical Studies on the Iron–Nickel–Aluminium System

Part III—TRANSFORMATIONS OF THE β AND β' PHASES

By A. J. Bradley, M.A., D.Sc., F.R.S.

SYNOPSIS

Photomicrographs have been taken to illustrate the course of the reactions that take place when the body-centred cubic structures of the Fe–Ni–Al system break up during cooling. The decomposition may take place either by the deposition of the face-centred cubic lattice, or by the splitting of the body-centred cubic lattice into two phases, one ordered, the other disordered. The former process is predominant at higher temperatures, and the latter at lower temperatures.

There is a maximum tendency for β, the disordered phase, to deposit α, the face-centred cubic phase, at about 1150° C., giving the highly irregular $\beta + \alpha$ structures. Under certain circumstances the whole of the precipitated α may redissolve before any of the ordered β' phase is formed from the disordered β lattice. In other cases the ordered phase is precipitated before the α phase redissolves, and a three-phase alloy of the type $\beta + \alpha + \beta'$ is formed. Similar effects occur in the decomposition of the β' phase. The α phase tends to redissolve, and so the $\beta' + \alpha + \beta$ structures are superseded by $\beta' + \beta$ structures at lower temperatures.

It is shown that high coercivity is exclusively connected with the incipient breakdown of the non-magnetic NiAl-rich ordered β' structure, which must remain predominant in order to form a continuous matrix. Under the most favourable circumstances this precipitate consists entirely of the lamellar ferromagnetic iron-rich β phase.

Fe_2NiAl is often quoted as a special case of a permanent-magnet alloy. Here the ordered body-centred cubic lattice may deposit the disordered phase without any face-centred cubic phase being formed. Small traces of the α phase may be ascribed to out-of-equilibrium processes.

Introduction

THE fact that Fe–NiAl alloys approaching the composition Fe_2NiAl could be made into permanent magnets has been attributed to the decomposition of the body-centred cubic phase on cooling. The most natural explanation was that the alloy consisted of two phases at low temperatures, and that the solubility limit of the body-centred cubic phase was displaced towards a higher aluminium content as the temperature fell; thus some of the α face-centred cubic constituent, derived from the Fe–Ni system, was precipitated. This explanation was based on microscopic observations of Koster,[1] which the present author repeated in Part I of this paper.[2]

X-ray work[3, 4, 5] indicated that, although the face-centred cubic phase could be produced under certain conditions, the alloys with the greatest coercivity contained little or none. Bradley and Taylor[6, 7, 8] and Kiuti,[9] independently in Japan, found that the ordered body-centred cubic lattice split up into two phases, one ordered, the other disordered. This breakdown has now been examined microscopically.[10] Bumm and Müller[11] doubted this explanation, but later it was partially accepted by Dannohl,[12] who concluded that the highest coercivity was attained when both reactions $\beta' \rightarrow \beta' + \alpha$ and $\beta' \rightarrow \beta' + \beta$ occurred simultaneously,[13] but it seems that this conclusion is possibly incorrect.

Body-Centred Cubic Phases β and β'

The phase β is characteristic of pure iron from the melting point down to 1390° C., and also below 907° C., whilst the β' structure is found in the nickel–aluminium system, ideally corresponding to the formula NiAl. This ordered arrangement has aluminium at the cube corners and nickel at the cube centres. The former may be replaced by considerable quantities of either nickel or iron, some of which remains in solid solution until the alloys are completely cooled.

At high temperatures, a continuous sequence of solid solutions might be expected, stretching from iron to NiAl, which, as the alloys cool, would break up into β and β'. In practice, there is present the face-centred cubic phase from the Fe–Ni system, which, between the temperatures of 907° and 1390° C., stretches uninterruptedly from pure iron to pure nickel. The replacement of 1·25% of Ni by Al (*see* Fig. 5, Part II[10]) gives a continuous sequence of body-centred cubic solid solutions, broken only by a narrow gap between the ordered and disordered phases. This gap widens rapidly on cooling below 950° C. and, as the temperature falls, the end phases gradually approach the ultimate compositions (Fe and NiAl) predicted by Snoek.[14] However, this asymptotic approach does not occur in the critical cooling range, which lies entirely above 750° C.

Precipitation of the Face-Centred Cubic α Phase from the β' Phase

During precipitation from the ordered body-centred cubic phase, four different structures (β', $\beta' + \alpha$, $\beta' + \alpha + \beta$, and $\beta' + \beta$) can exist. These structures can be distinguished by their photomicrographs; X-rays cannot be used.[15]

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Dr. Bradley was at the B.S.A. Group Research Centre, Sheffield when this paper was prepared.

IRON–ALUMINIUM DIAGRAM

A diagram, based on the work of Hansen[16] was reproduced in an earlier paper.[8] The austenitic loop is a small enclave, extending between 907° and 1390° C. from 0 to less than 2 at.-% of Al, within which the face-centred cubic structure is stable. No precise evidence is available, except from heating and cooling curves, which have the disadvantage of only yielding a single line, although the phase rule stipulates the existence of two boundary lines. Consequently, the nature of the two-phase region between the face-centred and body-centred cubic regions, which must theoretically exist,[17, 18] is unknown. The superlattices were investigated by Bradley and Jay,[19] and by Sykes and Evans.[20]

VERTICAL SECTIONS PARALLEL TO THE FE–AL SYSTEM

Three main types of vertical sections have been taken from the melting point down to 750° C., based on the results of quenching experiments made at temperature intervals of 100° C. In these experiments the specimens were held at the appropriate temperature for 2 days and were then given the following final heat-treatment after sawing into sections :

Temp., ° C.	Final Treatment
1350	½ hr.
1250	1½ hr.
1150	6 hr.
1050	1 day
950	4 days
850	16 days
750	9 weeks

The Section $\alpha + \beta$, 10% Ni

The solidus–liquidus curves of this section (Fig. 1*c*) fall as the aluminium content is increased, with a break at the peritectic composition at which the reaction liq. $+ \beta \rightarrow \alpha$ occurs. The α phase field is most extensive at about 1150° C. ; the β phase field is least extensive in relation to α at about 1100° C. A narrow two-phase region of the $\alpha + \beta$ type separates the α and β phase fields. The β phase decomposes to the $\beta + \beta'$ phase below 950° C. The $\alpha + \beta$ gap intersects the $\beta + \beta'$ gap to give the $\beta + \alpha + \beta'$ region of three-phase alloys.

The Section $\alpha + \beta'$, 25% Ni

The solidus–liquidus curves of this section (Fig. 1*g*) fall to a minimum at about 13% of Al, corresponding to the trough of the eutectic valley, liq. $\rightarrow \alpha + \beta'$. The α phase field, like the β phase field, is most extensive at the melting point and becomes rapidly less extensive as the temperature falls. A broad two-phase region of the $\alpha + \beta'$ type separates the α and β' phase fields. The β' phase decomposes to $\beta' + \beta$ below 970° C. The $\alpha + \beta'$ gap intersects the $\beta' + \beta$ gap to give the $\beta' + \alpha + \beta$ region of three-phase alloys.

The tie-lines rarely run anywhere near these sections, and for this reason more information may be obtained from other sections. For the $\beta + \beta'$ region the tie-lines run almost perpendicular to the Ni–Al system (*see* Part II[10]). For the $\alpha + \beta$ and $\alpha + \beta'$ regions, they begin at the melting point almost

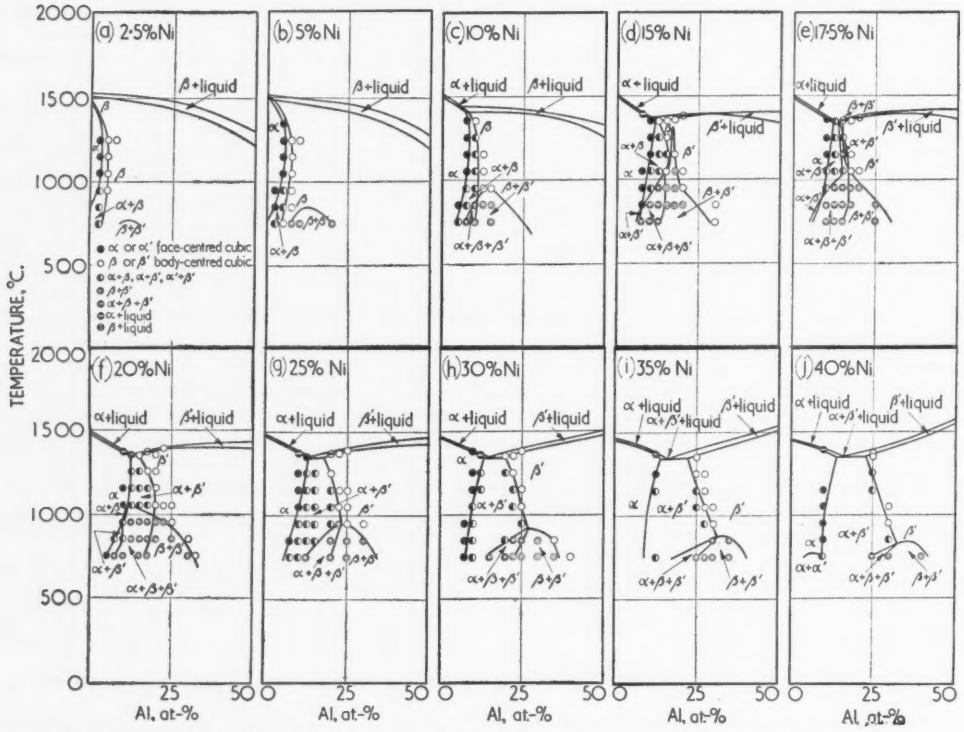

Fig. 1—Vertical sections parallel to the Fe–Al system for varying percentages of nickel

parallel to NiAl, but the direction changes considerably at lower temperatures (*see* Part I[2]).

The Transitional Sections, 15–20% Ni

15% Nickel (*Fig.* 1*d*)—Both $\alpha + \beta$ and $\alpha + \beta'$ phase fields are present. The $\beta + \beta'$ phase field extends to much higher temperatures. The β phase field is restricted to a narrow belt between the $\alpha + \beta$ and $\beta + \beta'$ phase fields. Its minimum temperature is 1030° C. The solidus and liquidus make contact at the saddle-point in the $\beta' +$ liq. area.

17½% Nickel (*Fig.* 1*e*)—The $\alpha + \beta'$ phase field appears at two separate points : at low temperatures on the α side, and at high temperatures on the β' side. The $\beta + \beta'$ phase field, intersecting the $\alpha + \beta$ and $\alpha + \beta'$ phase fields, leads to an extension of the $\alpha + \beta + \beta'$ region up to the melting point. The β phase field is disappearing at the melting point. Four-phase equilibria occur at the melt.

20% Nickel (*Fig.* 1*f*)—The $\alpha + \beta$ phase field is now restricted to a small region on the α side. The $\alpha + \beta'$ region is still separated into two portions : the main portion occurs above 990–1060° C. ; a detached portion below 940° C. belongs exclusively to the α side. The shape of the $\alpha + \beta + \beta'$ region is still abnormal. The $\beta + \beta'$ region already assumes the shape characteristic of higher nickel contents.

These three sections all require further investigation, and the present conclusions must not be regarded as final. A description of some of the difficulties that are encountered in this part of the diagram will be given in a later paper on the transformation of the face-centred cubic α phase.

LINK WITH FE–AL SYSTEM

Since the Fe_3Al phase does not exist at 750° C.,[19, 20] the ternary system consists only of the disordered and the simpler ordered structures of the FeAl (or NiAl) type, which, in the binary system, require at least 25 at.-% of Al. With less aluminium, the structures remain disordered until some nickel is added.

X-ray powder photographs show that a very small amount of nickel produces order after the alloys have been slowly cooled, even in almost pure iron.[7] This cannot mean that a structure such as $Fe_{18}NiAl$ becomes ordered *per se*, since a single phase in the ordered state could not give rise to visible superlattice lines. The true explanation lies in the deposition of the NiAl phase in the insular state, which has been described in earlier papers.[7, 8, 21] These islands were not observed in photomicrographs, because they are smaller (100 Å.) than the smallest visible particles (1000 Å.), but after nine weeks' heat-treatment at 750° C. they then became visible under oil immersion.

With the addition of only 2·5% of Ni (Fig. 1*a*) the splitting of the body-centred cubic phase is believed to occur just above 750° C. at 9–14 at.-% of Al. As the amount of added nickel increases, the splitting of the β phase takes place at progressively higher temperatures, reaching the melting point between 15 and 17·5% of Ni (Figs. 1*d* and *e*). The face-centred cubic loop widens rapidly as nickel is added ; it becomes concave in the $\alpha + \beta'$ region but the β or β' boundary remains concave only so long as the α boundary remains convex.

The $\alpha + \beta + \beta'$ phase field occurs wherever the $\alpha + \beta$, $\alpha + \beta'$, and $\beta + \beta'$ phase fields overlap. It may be seen from the vertical cuts (Figs. 1*a* to *j*) that there are three separate aspects on the problem :

(i) Between 7·5 and 15% of Ni, $\alpha + \beta$ intersects $\beta + \beta'$
(ii) At 17·5% of Ni, $\alpha + \beta$ intersects $\alpha + \beta'$
(iii) From 17·5% of Ni upwards, $\alpha + \beta'$ intersects $\beta + \beta'$.

The type of photomicrograph obtained from a triplex alloy depends entirely on which two duplex fields are combined. An X-ray powder photograph could not show the distribution of the phases, which is clearly exhibited by a photomicrograph. The microscopical problem is one of permutations, but the X-ray problem deals only with combinations.

Many of the difficult problems which arise through the peculiarities in the distribution of the phases, and which cannot be solved by X-rays, are also puzzling from the standpoint of the phase rule. These difficulties either arise from the precipitation of the α phase or are associated with the splitting of the $\beta + \beta'$ phases.

DESCRIPTION OF THE PHOTOMICROGRAPHS

The photomicrographs have been divided into two groups to illustrate the reactions of the β or β' phase. This distinction is necessary, since the permanent magnet alloys are only found in the second case.

REACTIONS OF THE β PHASE

The Reaction $\beta \rightarrow \beta + \alpha \rightarrow \beta \rightarrow \beta + \beta'$

The alloy Fe_6NiAl crystallizes from the melt as β, precipitates α at 1150° and 1050° C., and β' at 950° and 850° C.

Fig. 2—Fe 75%, Ni 12·5%, Al 12·5%. 1250° C. β. The specimen, which consists of two huge crystals only, is extremely brittle, splitting easily along the grain boundary. The etching characteristics depend entirely on which face is exposed. From other evidence there is proof that the grain that etches black is the one nearest to a (100) plane.

Fig. 3—Fe 75%, Ni 12·5%, Al 12·5%. 1150° C. $\beta + \alpha$. There is a copious white α precipitate evenly distributed throughout the specimen, with an irregular orientation and medium grain size (0·01–0·02 mm.). The particles are angular and have no regular shape.

Fig. 4—Fe 75%, Ni 12·5%, Al 12·5%. 1050° C. $\beta + \alpha$. The α phase is redissolving in the β phase. This corresponds to the lowered solubility of Al in the α phase and an increasing solubility of Fe in the β phase. The corresponding vertical section (12½% Ni) shows that the β phase passes through a point of minimum stability at about 1135° C. Below this temperature α is gradually reabsorbed until at about 1000° C. the alloy once more becomes single-phase.

Fig. 5—Fe 75%, Ni 12·5%, Al 12·5%. 950° C. $\beta + \beta'$. The alloy again becomes two-phase at about 970° C. The β' phase is now precipitated ; this may be proved by comparison with other characteristic alloys of the $\beta + \beta'$ region. The special features are :

(i) Smaller grain size, 5×10^{-5} to 2×10^{-4} cm.
(ii) Special shape, *i.e.*, with rounded corners and edges
(iii) Regular alignment to correspond with the β crystal orientation
(iv) A tendency to form rows of spots
(v) A tendency for spots to run into each other.

Fig. 6—Fe 75%, Ni 12·5%, Al 12·5%. 850° C. $\beta + \beta'$. The amount of the β' phase has increased. The spots are more spherical in shape and more uniform in size (between $0{\cdot}5 \times 10^{-4}$ and 10^{-4} cm.), with a greater tendency to run into each other. There is a definite grain boundary separating them from the matrix, which is much lighter in colour.

The Reaction $\beta \rightarrow \beta + \alpha \rightarrow \beta + \alpha + \beta' \rightarrow \beta + \beta'$

Fe_8NiAl, solidifying as massive β crystals (1350° C.), precipitates α at 1300° C. in very coarse grains. The structure remains unchanged down to 870° C. At 850° C. a mixed precipitation of α together with β′ forms on a fine scale, until finally at 750° C. the α phase redissolves completely and only β′ precipitates. The evidence for this chain of reactions is based on the nature of the precipitate, which changes completely at 850° C., in accordance with the requirements of the proposed diagram.

Fig. 7—Fe 80%, Ni 10%, Al 10%, 1150° C. $\beta + \alpha$. A very large quantity of the α phase is deposited on a large scale, α white, β black, although the alloy was originally single-phase. Nevertheless, the α phase is already disintegrating, having passed its point of maximum stability at about 1250° C.

Fig. 8—Fe 80%, Ni 10%, Al 10%, 850° C. $\beta + \beta' + \alpha$. The α phase has almost redissolved in the β phase, which no longer etches black. A scattered precipitate is formed on a much smaller scale. According to the diagram, this alloy is near the corner of the $\beta + \beta' + \alpha$ triangle at 850° C. This is confirmed by the presence of ribbons of the α phase.

Fig. 9—Fe 80%, Ni 10%, Al 10%, 750° C. $\beta + \beta'$. An interesting amount of a small rounded precipitate is present. The alloy is attributed to the $\beta + \beta'$ phase field. Faint boundaries of the β mosaic are visible in the background of the photomicrograph.

The Reaction $\beta \rightarrow \beta + \alpha \rightarrow \beta + \alpha + \beta'$

$Fe_{29}Ni_6Al_5$ solidifies as β at 1350° C., precipitates α at 1320° C., and finally precipitates β′ at 990° C.

Fig. 10—Fe 72·5%, Ni 15%, Al 12·5%, 1250° C. $\beta + \alpha$. The α phase (white) is very coarse, corresponding to the high temperature of its formation.

Fig. 11—Fe 72·5%, Ni 15%, Al 12·5%, 1150° C. $\beta + \alpha$. The α and β regions both contract with falling temperature, and consequently each portion of the alloy rejects some of the other constituent : $\alpha \rightarrow \alpha + \beta$; $\beta \rightarrow \beta + \alpha$.

Fig. 12—Fe 72·5%, Ni 15%, Al 12·5%, 1050° C. $\beta + \alpha$. The reaction $\alpha \rightarrow \alpha + \beta$ progresses further and the α precipitate, formed at 1250° C., becomes more eroded. The converse reaction $\beta \rightarrow \beta + \alpha$ is, however, already arrested at 1150° C., and it reverses at lower temperatures. At 1050° C. all the extra α precipitate goes back into solution, resulting in a clearly defined β background with an irregular α precipitate.

Fig. 13—Fe 72·5%, Ni 15%, Al 12·5%, 950° C. $\beta + \alpha + \beta'$. At 990° C. the alloy has entered the three-phase region, and the reactions are $\alpha \rightarrow \alpha + \beta'$ and $\beta \rightarrow \beta + \beta'$. A comparison between this photomicrograph and that at 1150° C. shows that the general distribution of the α and β phases remains unchanged, being fixed by the heat-treatment already received at 1300° C. The interior of the α grains is, however, filled with a fine white precipitate, which is lenticular instead of irregular in shape, indicating that β′ only is being ejected. The same reaction also takes place around the boundaries of the α phase. In the interior of the β phase a change similar to that observed in Fe_8NiAl at 950° C. occurs, the β′ precipitate being rounder in outline than the former α precipitate.

BORDERLINE CASES

Figs. 14 and 15—Fe 67·5%, Ni 17·5%, Al 15%. The most remarkable example of a complex series of transformations is illustrated by the alloy $Fe_{27}Ni_7Al_6$, which repeats the process of decomposition, *i.e.*, $\beta' \rightarrow \beta' + \alpha \rightarrow \beta + \alpha + \beta' \rightarrow \beta + \alpha \rightarrow \beta + \alpha + \beta' \rightarrow \beta + \beta'$. At the melting point (1350° C.) β′ crystallizes out ; at 1290° C. the α phase is precipitated first. Between 1200° C. and 1250° C. the β′ phase further decomposes into $\beta + \beta'$, without apparently affecting the α precipitate, thus giving rise to a three-phase alloy at 1150° C. (Fig. 14). At about 1100° C. this change is reversed, and at 1050° C. only the β phase appears to be precipitated (Fig. 15). The three-phase region is, however, again entered just below this temperature and a well-marked three-phase structure is present at 950° C. At 770° C., the three-phase structure is no longer formed and at 750° C. a clearly defined $\beta + \beta'$ alloy is found.

Fig. 16—Fe 67·5%, Ni 17·5%, Al 15%, 950° C. $\alpha + \beta + \beta'$. The alloy has again broken up into three phases. There are two distinct portions : $\alpha + \beta'$ and $\beta + \beta'$; the β′ phase therefore penetrates the whole structure.

Fig. 17—Fe 67·5%, Ni 17·5%, Al 15%, 750° C. $\beta + \beta'$. Only two phases can be discerned, which, from the phase diagram, must be β and β′ ; no α is present. The β′ phase is formed by precipitation from the β phase but it is hollow inside, indicating that the β′ phase is precipitating β on cooling ; this is in agreement with the phase diagram. The diagram is complicated because the alloy is on the borderline between the β and β′ phases just below the melting point. (Compare with the complicated vertical section at 17·5% nickel, Fig. 1*e*.)

REACTIONS OF THE β′ PHASE

These reactions concern the permanent magnet alloys. They fall into two main categories :

(*a*) $\beta' + \beta' + \beta$
and (*b*) $\beta' \rightarrow \beta' + \alpha \rightarrow \beta' + \alpha + \beta \rightarrow \beta' + \beta$.

The Reaction $\beta' \rightarrow \beta' + \beta$

This reaction is the simplest of all and, with one or two exceptions, occurs below 1000° C., the precise temperature depending on the composition ; *e.g.*, Fe_2NiAl is single-phase at 950° C. and two-phase at 850° C.

Fig. 18—Fe 50%, Ni 25%, Al 25%, 850° C. $\beta' + \beta$. The directions of vision in each of the three crystals shown are almost parallel to a 111 axis, and their traces are approximately equilateral triangles. For one grain the direction of vision is within 10° of a three-fold axis. The lamellae, which are about 30,000 Å. long in this crystal, are usually terminated by contact with other laminae running in other directions, so that the whole structure consists of a system of enclosed boxes with partitions running in any one of the three cube directions. The ordered structure forms the content of each box ; the disordered structure forms the walls of the box. Neighbouring lamellae are about 10,000 Å. (1μ) apart. The β phase is black and the β′ phase is white.

Fig. 19—Fe 50%, Ni 25%, Al 25%, 850° C. $\beta' + \beta$. When magnified by 4000 the lamellae can be seen to vary very considerably in thickness and to show bulges, especially at their points of intersection with each other. These bulges probably correspond to the original nuclei of precipitation, as in the alloy $Fe_6Ni_7Al_7$.[10] Neglecting such bulges, the lamellae are, on an average, about 1000 to 4000 Å. thick. No lamellae cross over one another, except when a bulge occurs, as would be expected if the bulge were an original point of precipitation. The waviness of the planes of precipitation is noteworthy.

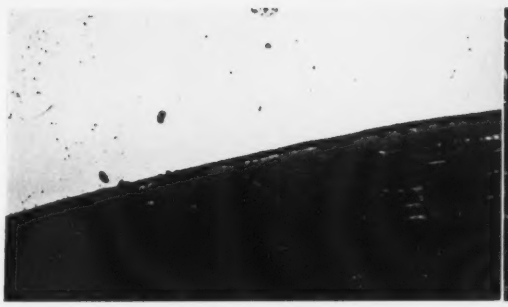

Fig. 2—Ni 12·5%, Al 12·5%, Fe balance, 1250° C.
β × 75

Fig. 3—Ni 12·5%, Al 12·5%, Fe balance, 1150° C.
$\beta + \alpha$ × 250

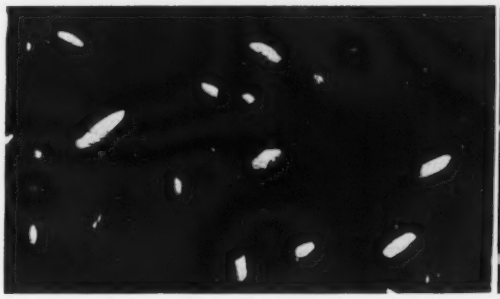

Fig. 4—Ni 12·5%, Al 12·5%, Fe balance, 1050° C.
$\beta + \alpha$ × 200

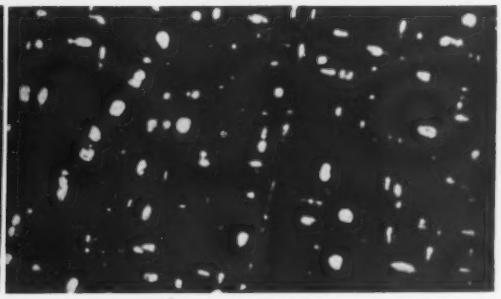

Fig. 5—Ni 12·5%, Al 12·5%, Fe balance, 950° C.
$\beta + \beta'$ × 1250

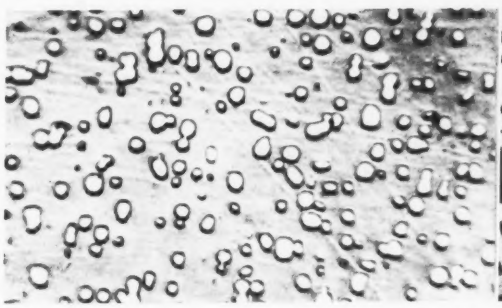

Fig. 6—Ni 12·5%, Al 12·5%, Fe balance, 850° C.
$\beta + \beta'$ × 2000

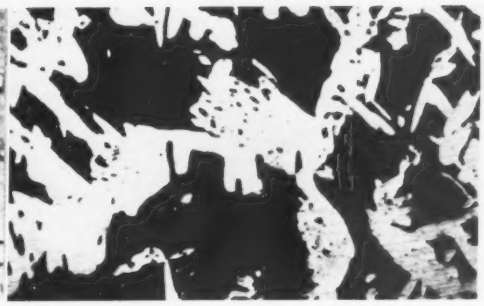

Fig. 7—Ni 10·0%, Al 10·0%, Fe balance, 1150° C.
$\beta + \alpha$ × 100

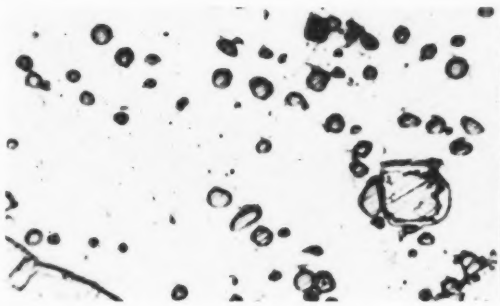

Fig. 8—Ni 10·0%, Al 10·0%, Fe balance, 850° C.
$\beta + \beta' + \alpha$ × 2000

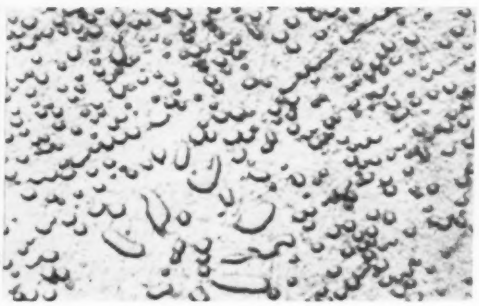

Fig. 9—Ni 10·0%, Al 10·0%, Fe balance, 750° C.
$\beta + \beta'$ × 2500

[*Bradley*
[*To face p.* 44

XUM

Fig. 10—Ni 15·0%, Al 12·5%, Fe balance, 1250° C.
$\beta + \alpha$ × 100

Fig. 11—Ni 15·0%, Al 12·5%, Fe balance, 1150° C.
$\beta + \alpha$ × 100

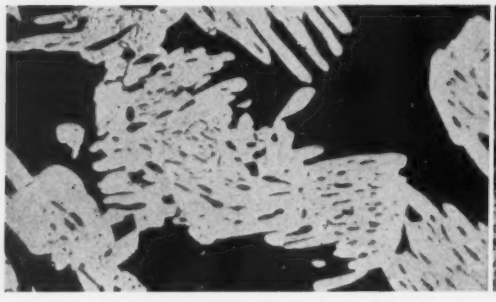

Fig. 12—Ni 15·0%, Al 12·5%, Fe balance, 1050° C.
$\beta + \alpha$ × 500

Fig. 13—Ni 15·0%, Al 12·5%, Fe balance, 950° C.
$\beta + \alpha + \beta'$ × 750

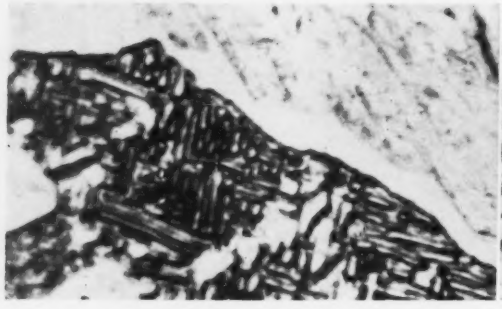

Fig. 14—Ni 17·5%, Al 15·0%, Fe balance, 1150° C.
$\beta' + \alpha + \beta$ × 3000

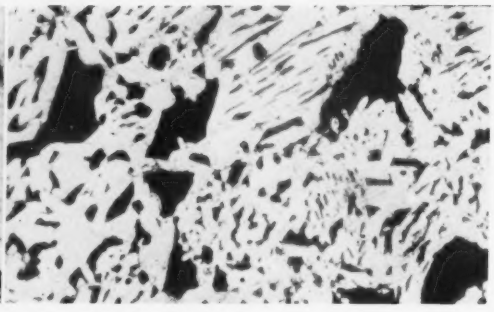

Fig. 15—Ni 17·5%, Al 15·0%, Fe balance, 1050° C.
$\alpha + \beta$ × 150

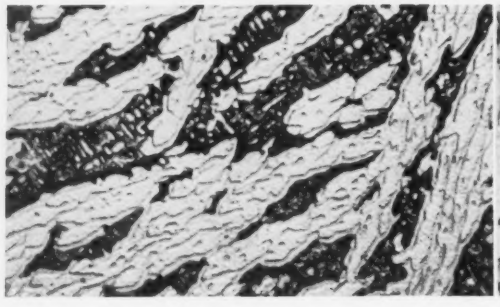

Fig. 16—Ni 17·5%, Al 15·0%, Fe balance, 950° C.
$\alpha + \beta + \beta'$ × 750

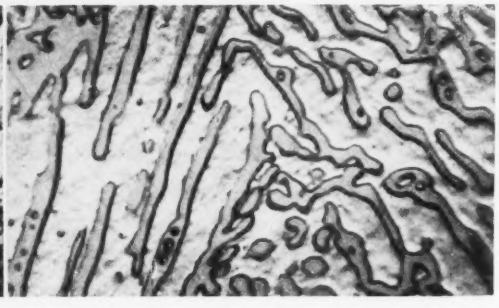

Fig. 17—Ni 17·5%, Al 15·0%, Fe balance, 750° C.
$\beta + \beta'$ × 2000

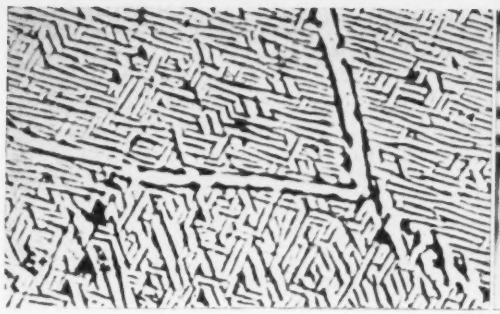

Fig. 18—Ni 25·0%, Al 25·0%, Fe balance, 850° C. $\beta' + \beta$ × 1000

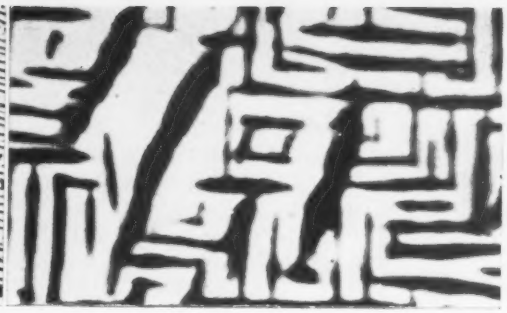

Fig. 19—Ni 25·0%, Al 25·0%, Fe balance, 850° C. $\beta' + \beta$ × 4000

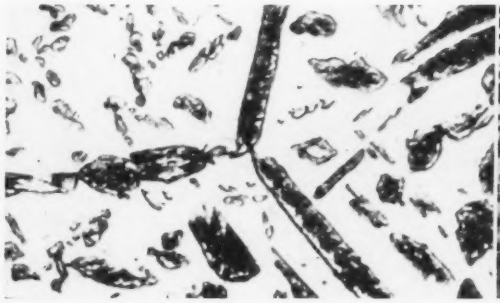

Fig. 20—Ni 30·0%, Al 22·5%, Fe balance, 1050° C. $\beta' + \alpha$ × 400

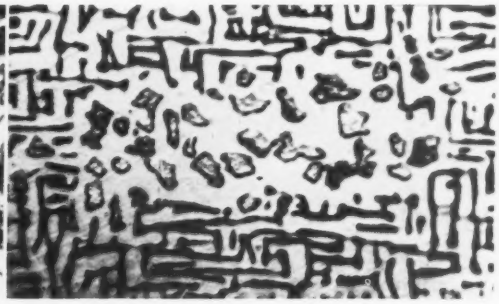

Fig. 21—Ni 30·0%, Al 22·5%, Fe balance, 850° C. $\beta' + \alpha + \beta$ × 2000

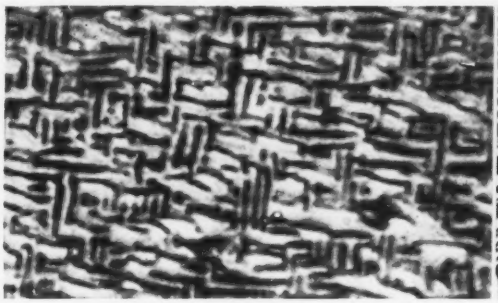

Fig. 22—Ni 30·0%, Al 22·5%, Fe balance, 750° C. $\beta' + \beta$ × 4000

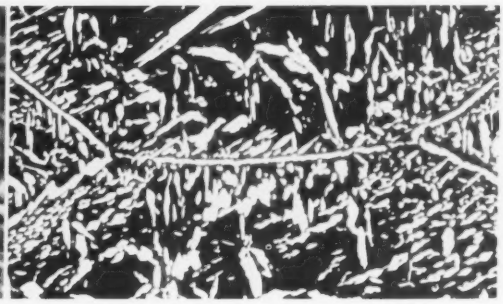

Fig. 23—Ni 20·0%, Al 17·5%, Fe balance, 1050° C. $\beta' + \alpha$ × 100

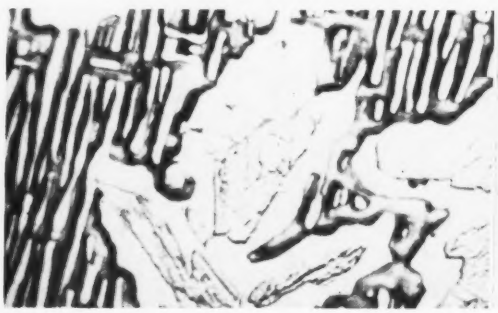

Fig. 24—Ni 20·0%, Al 17·5%, Fe balance, 950° C. $\beta' + \alpha + \beta$ × 2000

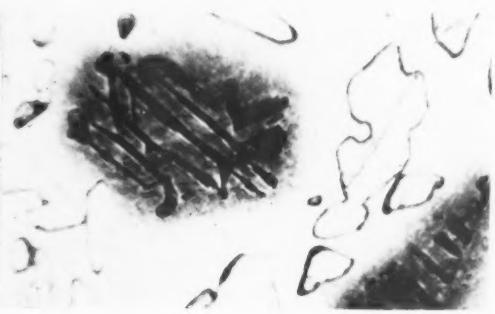

Fig. 25—Ni 22·5%, Al 20·0%, Fe balance, 950° C. $\beta' + \alpha + \beta$ × 2000

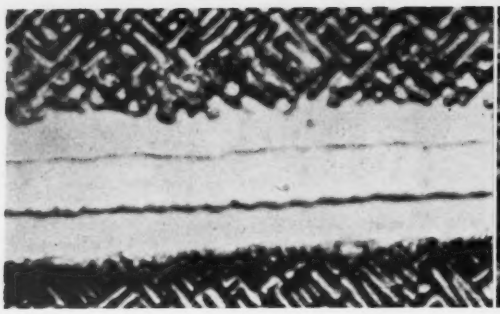

Fig. 26—Ni 22·5%, Al 20·0%, Fe balance, 850° C.
$\beta + \beta' (+ \alpha)$ × 3000

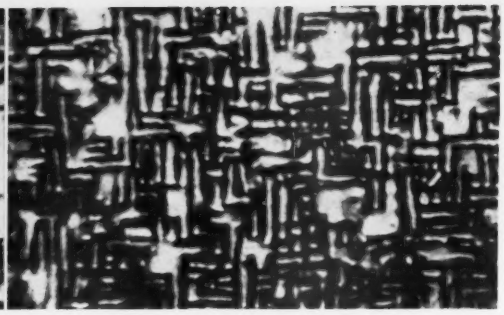

Fig. 27—Ni 22·5%, Al 20·0%, Fe balance, 850° C.
$\beta + \beta'$ × 3000

Fig. 28—Ni 22·5%, Al 20·0%, Fe balance, 750° C.
$\beta + \beta'$ × 4000

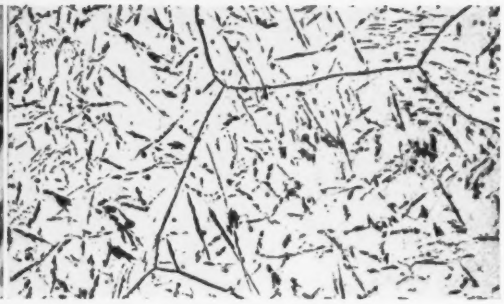

Fig. 29—Ni 35·0%, Al 27·5%, Fe balance, 950° C.
$\beta' + \alpha$ × 50

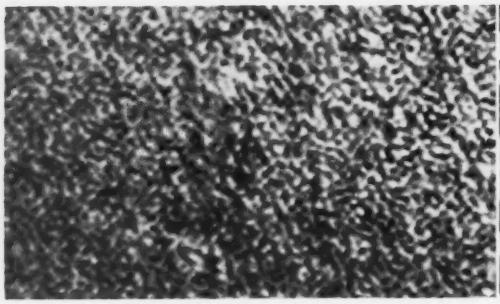

Fig. 30—Ni 35·0%, Al 27·5%, Fe balance, 750° C.
$\beta' + \beta$ × 4000

Fig. 31—Ni 25·0%, Al 20·0%, Fe balance, 950° C.
$\beta' + \alpha$ × 1000

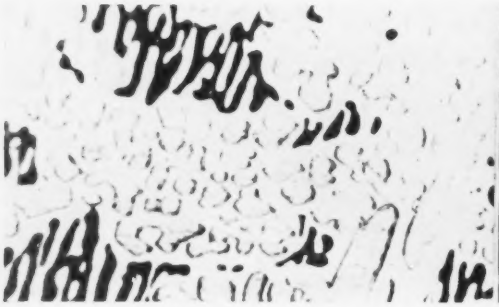

Fig. 32—Ni 25·0%, Al 20·0%, Fe balance, 850° C.
$\beta' + \alpha + \beta$ × 2000

Fig. 33—Ni 25·0%, Al 20·0%, Fe balance, 750° C.
$\beta' + \beta (+ \alpha)$ × 2500

The Reaction $\beta' \rightarrow \beta' + \alpha \rightarrow \beta' + \alpha + \beta \rightarrow \beta' + \beta$

This sequence of transformations is extremely common in the Fe–Ni–Al system. The β′ phase is formed direct from the melt, first precipitating α and then β, with the α phase finally dissolving. For example, $Fe_{19}Ni_{12}Al_9$, which is still homogeneous at 1250° C., decomposes at 1230° and 850° C., and partially recombines just below 750° C.

Fig. 20—Fe 47·5%, Ni 30%, Al 22·5%, 1050° C. $\beta' + \alpha$. This shows the characteristic precipitation of α in the grain boundaries and in the interior of the crystals. The matrix is no longer darkened, although the precipitate is.

Fig. 21—Fe 47·5%, Ni 30%, Al 22·5%, 850° C. $\beta' + \alpha + \beta$. The alloy has entered the three-phase triangle. Isolated irregular grains of α are still distinguishable. The β phase forms an almost continuous network. The average spacing of the lamellae is about 1μ.

Fig. 22—Fe 47·5%, Ni 30%, Al 22·5%, 750° C. $\beta' + \beta$. There is no trace of the α phase. The β phase forms a continuous lattice, but with a much finer mesh. The structure is less regular. The average mesh is about 3500 Å. or approx. one-third of its size at 850° C. Good photographs of the precipitates formed at 750° C. cannot be obtained. The alloy $Fe_{25}Ni_9Al_7$ precipitates α at 1240° C., β at 1000° C., and redissolves α at 800° C.

Fig. 23—Fe 62·5%, Ni 20%, Al 17·5%, 1050° C. $\beta' + \alpha$. This is one of the few instances where the β′ phase etches black. The colour reversal results from the greater instability, or possibly from the higher iron content. The α phase is mainly deposited in and near the grain boundaries. The interior of each grain is full of a copious α deposit.

Fig. 24—Fe 62·5%, Ni 20%, Al 17·5%, 950° C. $\beta' + \alpha + \beta$. The β phase is deposited as the α phase redissolves. The background of the crystal is white instead of black, *i.e.*, the β′ phase no longer stains. This is probably because it is no longer so severely stressed by supersaturation. The α precipitate contains definite markings caused by its own internal stresses, which have not yet been relieved, since the α phase with 20% of Ni is still highly supersaturated after quenching.

The β phase is precipitated as a continuous grey network, leaving the β′ phase imbedded inside it. This structure has the characteristics of β precipitating β′ (lenticular) and β′ precipitating β (network). This is in accordance with the position of the alloy on the median drawn from the α apex of the three-phase triangle to a point midway along its β–β′ side.

Sporadic Occurrence of α Precipitate in Slabs in the β′ Grain Boundaries

There are many alloys in the $\beta' + \beta$ two-phase region, in which the α phase is deposited, in the grain boundaries only and not inside the crystals, in slabs thicker than 10^{-4} cm. (1μ). The thickness of the slabs is almost independent of the position of the alloy in the phase diagram. The slabs either appear wholly or not at all.

Fig. 25—Fe 57·5%, Ni 22·5%, Al 20%, 950° C. $\beta' + \alpha + \beta$. Solidifying at 1370°, this alloy enters the $\alpha + \beta$ area at 1160° C., passing into the three-phase triangle at 970° C. The photograph shows the β′ corner of the three-phase field, where the alloy is just beginning to precipitate the other two phases. The contrast between the white α grains and the black β shape is nowhere better seen.

Fig. 26—Fe 57·5%, Ni 22·5%, Al 20%, 850° C. $\beta + \beta'(+ \alpha)$, (grain boundary). The α precipitate has entirely redissolved in the interior of the crystal grains, leaving only a plate, 3μ thick, in each grain boundary. This means that about 1 p.p.10^3 of the crystal is in the α form, since each grain is about 1 cm. long. Because this is essentially a surface phenomenon considerably more than this amount is observed on an X-ray powder photograph. As the crystal is ground up more surface is exposed and consequently more of the α phase is formed. No α precipitate is deposited in the interior of the crystal grains.

The $\beta + \beta'$ network indicates a position nearly midway between the β and β′ ends of the corresponding tie-lines. The alloy is placed just outside the three-phase triangle, since α is only found when the crystals are out of equilibrium, owing to surface energy. The average spacing of the $\beta + \beta'$ network is about 5000 Å. The β phase is continuous and the β′ phase is discontinuous.

Near the grain boundaries only α and β′ are present, the β phase being entirely withdrawn into the interior of each crystal. The total thickness of the ' abnormal ' structure in the grain boundaries is 6×10^{-4} cm. (6μ), *i.e.*, about 20,000 atoms thick. This gives 10,000 atoms as the depth from the grain boundary to which the $\alpha + \beta'$ irregularity penetrates into the crystal lattice.

Fig. 27—Fe 57·5%, Ni 22·5%, Al 20%, 850° C. $\beta + \beta'$, (interior of grain). This is a section parallel to a cube face showing white vertical slices of β′ parallel to the 100 and 010 faces ; flat sections of β are visible in the 001 surface. These appear to be about 1·5μ in length and breadth, and about ¼μ in thickness.

Fig. 28—Fe 57·5%, Ni 22·5%, Al 20%, 750° C. $\beta + \beta'$. Two changes are apparent : the white α plates in the grain boundaries are absent, since the difference in free energy between the interior and the surface is no longer sufficient to stabilize them, and the regular maze structure, characteristic of 850° C., is breaking up. The material is no longer uniform, but is dividing into separate patches, consisting of β separating from β′ in plates, and β′ precipitating from β in the form of globules. Thus, heat-treatment at a lower temperature has had a coarsening effect. The obvious explanation is that along this line of compositions (*i.e.*, adjacent to the three-phase triangle) the lattice spacings of the β and β′ phases differ very much more than at higher temperatures. The differences become less away from the three-phase triangle, until finally the spacings become equal. These coarse structures are limited to compositions on the β side of the gap, fairly near the centre, and just outside the three-phase triangle. They appear to arise from a tendency for the iron-rich phase to segregate from the main body of the alloy.

An example of the contrast between the feathery α precipitate and the fine mosaic β precipitate is found in $Fe_{15}Ni_{14}Al_{11}$. To bring the two structures to the same scale one is magnified by 50, the other by 4000. This alloy passes through the three-phase region between 840° and 790° C. and there was, therefore, no observed example of the three-phase state.

Fig. 29—Fe 37·5%, Ni 35%, Al 27·5%, 950° C. $\beta' + \alpha$. A very low magnification is used to show the overall effect. The grains are about 1 mm. in size, and show black lines in the grain boundaries, which, as seen from photographs with higher magnifications, indicate the presence of the α phase. Inside the grains are feathery α crystals.

Fig. 30—Fe 37·5%, Ni 35%, Al 27·5%, 750° C. $\beta' + \beta$. The β precipitate is just visible with the very much higher magnification. The alloy $Fe_{11}Ni_5Al_4$ crosses into the three-phase region at 930° C. It should pass into the $\beta' + \beta$ area at 780° C. ; the 750° C. photograph is, however, rather ambiguous.

Fig. 31—Fe 55%, Ni 25%, Al 20%, 950° C. $\beta' + \alpha$. The α phase is ejected in large irregular grains.

Table I

RELATION BETWEEN COERCIVE FORCES AND SPLITTING PHENOMENA

Alloy No.	23	25	27	33	35	37	45	46	47
Fe, %	65	60	55	64	59	54	58	55·5	53
Ni, %	25	30	35	25	30	35	30	32·5	35
Al, %	10	10	10	11	11	11	12	12	12
Fe, at.-%	59	55	50½	57½	53	49	52	50	48
Ni, at.-%	22	26	30½	21½	26	30	25½	28	30
Al, at.-%	19	19	19	21	21	21	22½	22	22
H_c as-cast	385	525	600	410	600	590	580	600	600
H_c annealed at 600° C.	400	550	625	430	620	650	595	630	650
H_c annealed at 650° C.	410	580	640	450	620	670	600	650	690
H_c annealed at 700° C.	405	585	640	450	615	660	585	630	670
H_c annealed at 750° C.	380	570	630	430	600	630	550	615	630
H_c annealed at 1000° C.	140	180	170	150	120	160	180	150	120
Structure at 750° C.	$\beta+\beta'$	$\alpha+\beta+\beta'$	$\alpha+\beta+\beta'$	$\beta+\beta'$	$\beta+\beta'$	$\alpha+\beta+\beta'$	$\beta+\beta'$	$\beta+\beta'$	$\beta+\beta'$
Reactions	2–3–2	2–3	2–3	1–2	2–3–2	2–3	2–3–2	2–3–2	2–3–2
Structure at 1000° C.	$\alpha+\beta'$	$\alpha+\beta'$	$\alpha+\beta'$	β'	$\alpha+\beta'$	$\alpha+\beta'$	$\alpha+\beta'$	$\alpha+\beta'$	$\alpha+\beta'$

Fig. 32—Fe 55%, Ni 25%, Al 20%, 850° C. $\beta'+\alpha+\beta$. The background consists of β', which precipitates both β and α. The α phase is in small grey granules of irregular shape, whereas the β phase forms a continuous black network with a regular spacing.

Fig. 33—Fe 55%, Ni 25%, Al 20%, 750° C. $\beta'+\beta(+\alpha)$. The α phase is being steadily replaced by β and, according to the diagram, this alloy should already be $\beta'+\beta$, all the α having redissolved. The β phase forms two distinct types of deposit : it either agglomerates or forms the network structure.

Chain Reactions

Two chain reactions, which concern the β' phase, are included for completeness, although they are of a quite different character. The alloy $Fe_6Ni_{23}Al_{11}$ passes through the following series of reactions :

$$\beta' \rightarrow \beta'+\alpha \rightarrow \beta'+\alpha+\alpha'$$

and the alloy $Fe_3Ni_{28}Al_9$ changes in the following way :

$$\beta'+\alpha \rightarrow \beta'+\alpha+\alpha' \rightarrow \beta'+\alpha' \rightarrow \alpha'$$

The explanation of these two reactions, which can only be sought with reference to the NiAl system, will be given in a later paper.

FERROMAGNETISM AND THE β' TRANSFORMATIONS

With one exception, no alloy breaks up into $\beta'+\beta$ above 1000° C., and it is therefore possible to test whether the large coercive forces (H_c) developed in these alloys are directly related to the splitting phenomenon. Figures given by Kiuti[21] are quoted in Table I. The atomic composition has been included to facilitate comparison with the vertical cuts. The reactions can thus be traced and the structures at 1050° C. and 750° C. can be determined. The high coercivity is directly associated with transformations occurring between 1050° and 750° C. These transformations are of three kinds, as follows :

(2–3–2) $\alpha+\beta \rightarrow \alpha+\beta+\beta' \rightarrow \beta+\beta'$
(2–3) $\alpha+\beta \rightarrow \alpha+\beta+\beta'$
(1–2) $\beta' \rightarrow \beta+\beta'$

There is evidently no relation between the type of reaction and the coercivity. Since the highest coercivity is associated with the lowest iron content, it may be concluded that the coercivity is primarily related to the relative proportions of the β and β' phases, the proportion of β' being highest when the coercivity is greatest.

Three compositions, $Fe_{23}Ni_9Al_8$, $Fe_{11}Ni_5Al_4$, and $Fe_{19}Ni_{12}Al_9$, are represented in Table I by alloys 23 and 33, 25, and 47 respectively. At 750° C. the relative proportions of the β and β' phases are 4 : 3, 12 : 11, and 3 : 4. The maximum recorded coercivities are 450, 580, and 690 respectively. A comparison of the photomicrographs at 750° C. shows that these three structures are quite different. The β' phase is precipitated from β and the β phase is precipitated from β', in quite different ways.[10] The photograph for $Fe_{23}Ni_9Al_8$ at 750° C. (Fig. 28) shows a mixture of these two processes, and the coercivity is only moderate. In $Fe_{11}Ni_5Al_4$ (Fig. 33) the β phase is ejected from β' in two different ways, and some α is still present. The coarser form of the β precipitation is not conducive to the highest coercivity. In $Fe_{19}Ni_{12}Al_9$ (Fig. 22), where the coercivity is at a maximum, there is a continuous $\beta'+\beta$ structure ; β is precipitated in discontinuous plates from a continuous β' matrix. This is because the alternate β and lamellae are always equal in breadth, so that with β' in excess, β must be discontinuous. (With β in excess, that phase would have to be continuous ; the lamellar structure then becomes unstable, with a consequent fall in coercivity.)

It may therefore be concluded that for the state of highest coercivity the matrix is formed from a continuous non-magnetic highly ordered NiAl phase. On this is superposed a finely dispersed precipitate composed of almost pure iron in lamellar form. After nine weeks at 750° C. the lamellae become about 2000 Å. thick, and are about 4000 Å. apart, but are in a state of maximum coercivity ; as Burgers and Snoek[4] have shown, there are sidebands to the X-ray lines even after a few seconds. The sidebands are caused by the iron lamellae occurring on an atomic scale. Bradley,[22] and Lipson and Daniel[23] have already shown that similar sidebands occur during the break-up of an alloy of the composition Cu_4FeNi_3, which was discovered during an investigation of the ternary system Fe–Cu–Ni.[24] A metastable intermediate tetragonal structure is assumed. Similarly,

Lipson, Schoenberg, and Stupart[25] showed that a metastable tetragonal structure was also formed in FePt, which has a very high coercivity.

Acknowledgments

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A Note on Filiform Corrosion

By F. Hargreaves, A.R.S.M., D.I.C., F.R.I.C., F.I.M.

SYNOPSIS

Filiform corrosion has been induced on polished carbon steel specimens exposed to the atmosphere. Corrosion tracks, originating from slag inclusions, had developed after 24 hours' exposure ; they showed brilliant interference colours. Some filiform corrosion tracks occurred on coated specimens—the longer the specimen was exposed before the coating was applied, the more numerous were the tracks.

The incipient corrosion of steel, whether given a protective coating or not, often takes place by the formation of characteristic tracks. This type of corrosion has been observed on lacquered steel specimens by Sharman,[1] and much work has been carried out by Vernon[2, 3, 4] on the atmospheric corrosion of uncoated steel. Steel microsections, on standing in the laboratory of the Locomotive Works, British Railways, Eastleigh, developed tracks similar to those shown in Fig. 1. The tracks differ in width, but each is fairly uniform in width along its length. The narrow track shows first orders green and the wider track shows first to second orders green interference colours.

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The Locomotive Works are about 8 miles north-east of Southampton Water and the laboratory is within the works, which include forge, foundries, etc. The room in which the specimens were exposed had roof lights and was not used for analytical work.

UNCOATED SPECIMENS

Observations were mainly carried out on normalized carbon steels with a tensile strength of 35–40 tons/sq. in. The specimens were given a normal metallurgical polish and were exposed in the laboratory under a

Table I

WIDTH OF CORROSION TRACKS AND THEIR INTERFERENCE COLOURS

System No.	Interference Colours	No. of Observations	Width × 10^{-5} cm.	
			Range	R.M.S.
1	Dark	4	3·8– 5·0	4·05
2	1st order green	6	6·8– 9·3	7·5
3	1st orders green to red	15	9·2–21·8	15·9
4	1st to 2nd orders green	13	16·8–24·9	20·3
5	1st order green to 2nd order red	10	22·5–37·4	29·0

clock-glass supported by two blocks of wood, to give some protection from dust but to allow access of air.

Observation showed that after a track had formed many small changes in detail might occur. Twenty-eight days after formation, the narrow track in Fig. 1 showed apparent inflation and the collapse of bubbles in several places. Light location scratches on this microsection had no detectable influence on the initiation or development of the corrosion tracks. Observed rates of growth were 0·0032–0·0052 cm./day. Tracks showing the same range of interference colours differed considerably in width, as shown in Table I.

A microsection, cut from the fractured end of a tensile test piece of ductile steel, was polished and etched, then repolished and exposed. After 24 hr. it showed numerous corrosion tracks, each originating from a slag inclusion and growing approximately in the direction of polishing. It was repolished, soaked in alcohol for ½ hr. to wash out the damaged inclusions, dried, and exposed. Even after standing for three days, very few tracks originating from inclusions were present.

A microsection, given a French emery 000 finish, developed, within two days, corrosion tracks similar to those described, but tending to run along the valleys formed by the scratches. Etched microsections developed normal tracks on exposure. In general, 24 hours' exposure resulted in track formation on all specimens. Minute spherical drops, which sometimes persisted, apparently unchanged, for several weeks, were often seen on the surface of the specimens.

In further experiments specimens were exposed to the laboratory air after it had been passed through cotton wool. A polished specimen was soaked in alcohol for ½ hr., was dried, and was put in a bottle through which the filtered air was drawn at intervals. At the end of 16 days no corrosion tracks were found. The specimen was repolished and drops (about 10 × 10^{-5} cm. dia.) of an aqueous solution of 2% NaCl and 0·25% $MgCl_2$ were deposited on it using an atomizer. After 7 hr., 60–70 corrosion tracks similar to the narrow one shown in Fig. 1 had formed. Figure 2, a micrograph of this specimen, shows, in addition to the filiform corrosion on the right, other tracks which grew by successive, approximately circular, accretions.

COATED SPECIMENS

To determine the effect of a protective coating a polished microsection was given a colourless cellulose finish a few minutes after polishing. Three days later tracks approximately 0·0003 cm. wide (Fig. 3) were observed. These were the only tracks on the specimen and they showed brilliant interference colours. Experiment showed that the longer the specimen was exposed before the coating was applied, the more numerous were the tracks. This supports the view that the tracks originate from deposited droplets.

Figure 4 shows corrosion tracks found on a steel macrosection, which had been given a coat of boiled linseed oil seven years previously. Three of the four tracks are seen to start at the edge of the specimen. A similar specimen was treated with caustic soda, to remove the oil film; the tracks remained as tracks of 'rust' generally 0·005–0·01 cm. wide. The growth of similar tracks has been followed by scraping a small area to remove the oil film and initiating corrosion by NaCl solution. The rate of growth was generally 0·0035–0·0077 cm./day, although it completely stopped for three days during a very cold spell.

Filiform corrosion has been observed on the black finish on the inside of a motor car, where the finish is rather thin. Nickel-plated ashtrays in the same car showed filiform corrosion (*see* Fig. 5). The nickel (0·0003 in. thick) is deposited directly on the steel. A chromium-plated electric fire showed some similar tracks but in some regions there was incipient corrosion from centres and no filiform corrosion. Filiform corrosion has been observed on the enamelled steel case of an alarm clock, whereas an enamelled tinned steel case showed no filiform corrosion. No such corrosion occurs on tinplate and galvanized steel, although rusting has often been observed.

Experiments suggested that filiform corrosion could not be induced on steel which had been given a phosphate treatment followed by two coats of lacquer, whereas, without the phosphate treatment, it was readily formed.

The author has observed filiform corrosion on painted cast iron, and also on an aluminium alloy moulding (of unknown composition) used for fixing aluminium sheet panels on the walls of a shop. War emergency food tins that were given a protective lacquer instead of a coat of tin, show very well-developed tracks of the same magnitude as those shown in Fig. 4.

Acknowledgments

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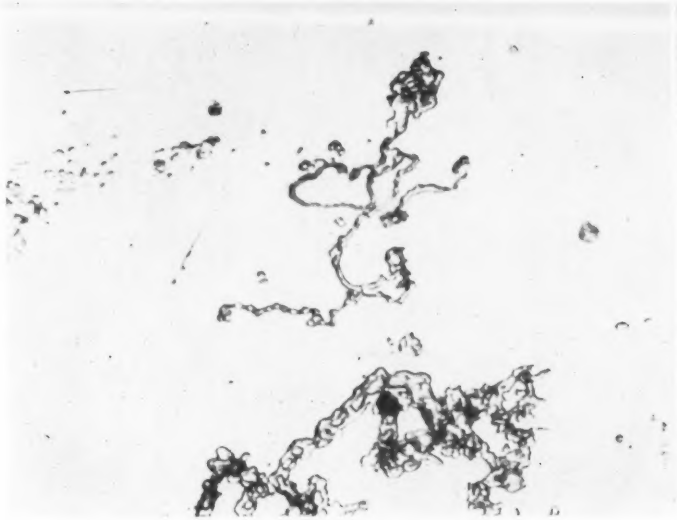

Fig. 1—Narrow corrosion track on polished steel, 28 days after formation × 1650

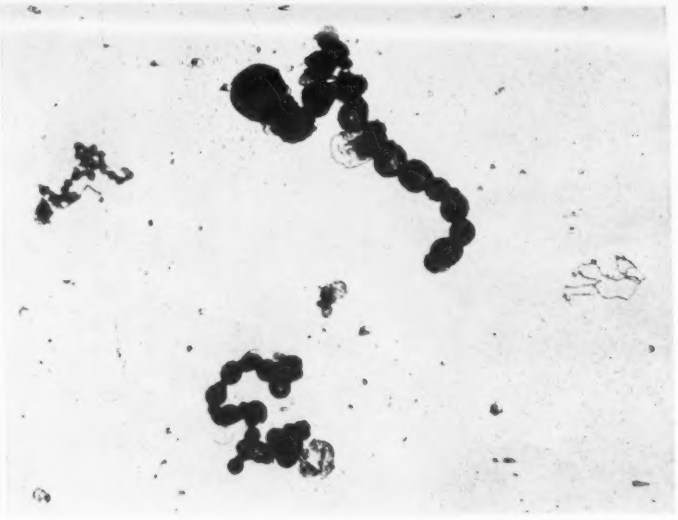

Fig. 2—Chains of round corrosion spots, filiform corrosion, on specimen used for 'filtered air' experiment, after repolishing and treating with 2% NaCl, 0·25% $MgCl_2$ solution × 160

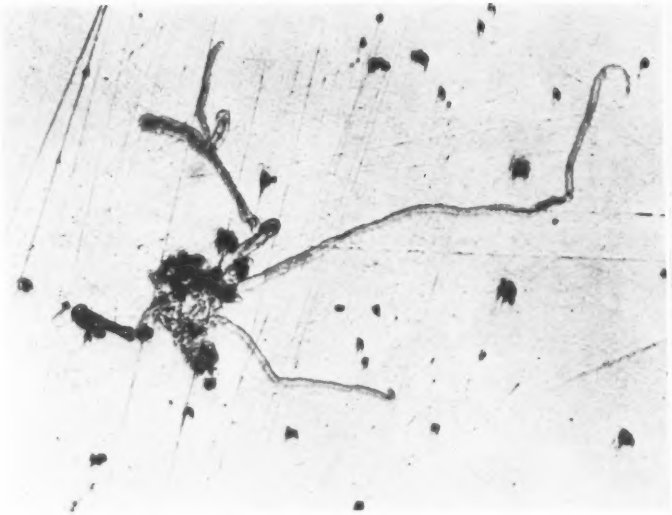

Fig. 3—Corrosion tracks on polished steel with protective coating of colourless cellulose finish × 260

Fig. 4—Corrosion tracks on macrosection of steel with a coating of linseed oil × 12

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Fig. 5—Corrosion tracks on a nickel-plated steel ashtray × 12

Occurrence of Sigma Phase in a High Chromium–Nickel Steel and the Effect of Carbon Content

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SYNOPSIS

A study has been made of the effect of 0·06–0·29% of carbon on the sigma-phase formation in a commercial 25/15 Cr–Ni steel.

The mode of formation of sigma phase from duplex austenite–ferrite, austenite–carbide, or austenite structures has been investigated by consideration of the changes produced by heating at 700° and 900° C. for periods of up to 2000 hr. after solution treatment carried out over a range of temperatures from 950° to 1250° C. The results of microscopical and X-ray examination are given, and these and certain constitutional aspects are discussed.

Attention has been paid to the etching characteristics of the various phases and constituents that may be present in the microstructure.

Introduction

THE influence of carbides and sigma phase on the physical, chemical, and mechanical properties of chromium–nickel alloy steels has been widely reviewed within the last twenty years.[1–4] The subject has become more important with the development of the higher alloyed steels for use in gas-turbine and jet-propulsion engines.

It is desirable that easy and efficient methods of identification of carbides and sigma phase should be available. Many of the methods of etching specimens for microscopical examination, with the object of identifying one particular phase, often fail to indicate the presence or nature of other phases. In the authors' experience, the etching characteristics of sigma phase are partly dependent upon its composition and particle size, and therefore the interpretation of the microstructure is frequently uncertain.

When the formation of both carbide and sigma phase are studied, the following difficulties are encountered :

(i) Similarity in occurrence, particularly at grain boundaries or along crystallographic planes

(ii) Both constituents are hard, so that the efficacy of the 'scratch test,' or even of the micro-hardness test, is reduced

(iii) Both constituents can be formed in the same temperature range and from similar initial microstructures

(iv) Many etching reagents of the type used for high-alloyed austenitic or austenitic–ferritic steels, even when used under several conditions, fail to distinguish the constituents as separate entities.

These difficulties have been at least partly overcome by the methods employed in the work described in this paper. It is generally necessary to use at least two etching reagents for microscopical identification, and the verification of constituents by means of X-ray analysis is a valuable additional measure.

This investigation has been concerned with the occurrence of sigma phase and the influence of varying carbon content in a commercial type 25/15 Cr–Ni steel reheated at temperatures of 700° and 900° C., after initial solution treatments at temperatures within the range 950° to 1250° C. In addition to microscopical examination of all the samples and X-ray examination of selected samples, a simple magnetic balance was used as a test for the presence of untransformed ferrite.

Composition and Heat-Treatment of Steels

The analyses of the steels used in the investigation were as follows :

%	SG.6679	SG.6680	SG.6681	SG.6682
Carbon	0·06	0·09	0·19	0·29
Silicon	1·77	1·75	1·68	1·72
Manganese	0·65	0·65	0·61	0·63
Chromium	24·68	25·32	25·44	25·12
Nickel	15·05	15·13	15·15	15·08

The steels were made in an experimental 18-lb. H.F. furnace and were cast into $2\frac{1}{2}$-in. square ingots, which were then forged to $\frac{1}{2}$- or $\frac{3}{4}$-in. dia. bar. Specimens $\frac{1}{4}$ in. long were taken from each cast and were prepared for microscopical examination after the following heat-treatments :

(i) Solution treatment at temperatures of 950°, 1050°, 1150°, and 1250° C., for 4 hr., followed by water quenching

(ii) Treatment as in (i), with further heating at 700° and 900° C. for periods of 4, 100, 1000, and 2000 hr., followed by air cooling.

MICROSCOPICAL EXAMINATION

Microscopical examination of the structure of the samples was carried out using different methods of etching, of which the most generally useful was an electrolytic etch in an oxalic acid solution. The other methods were used for confirmation of the

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results obtained with this reagent, and for distinguishing more definitely between the carbide and sigma phase.

All the samples were electrolytically etched in a 10% solution of oxalic acid in water. The current density was standardized at 50 m.amp./sq. cm., although the etching period varied from 5 to 100 sec. This etch outlined the ferrite and sigma phase and darkened carbides, and what was considered to be a ferrite–sigma transition aggregate was outlined and slightly darkened.

Samples Solution-Treated at 950° C. (Table I*a* and Fig. 1)

The low solution-treatment temperature of 950° C. was found to be insufficient to materially change the structure of the forged bars or to effect complete austenitization of any of the steels. The structure of the 0·06 and 0·09% C steels consisted of austenite with a ferrite–sigma transition aggregate, with a small amount of carbide present at the grain boundaries. The 0·19 and 0·29% C steels showed a coarser-grained austenite structure with carbide mainly at the grain boundaries.

The structure of the 0·06% C steel after reheating at 700° C. showed almost complete transformation of ferrite to sigma phase after 2000 hr. A grain-boundary precipitation of carbide evident in the early stages coalesced with increased time at temperature. On heating at 900° C., almost complete transformation of ferrite to sigma phase was achieved after 1000 hr., whilst very little carbide was evident after 100 hr. The structural changes of the 0·09% C steel were similar, although at 900° C. the rate of sigma-phase formation was increased and was almost complete after 100 hr.

After reheating at 700° C., the two higher carbon steels showed pronounced precipitation of carbides both within the grains and at the grain boundaries, followed by the formation of sigma phase at the

Table I*a*

MICROSCOPICAL ANALYSIS OF STEELS*

Solution-treated at 950° C. for 4 hr., water-quenched, and reheated

Time and Temp. of Reheating	SG.6679 (0·06% C)	SG.6680 (0·09% C)	SG.6681 (0·19% C)	SG.6682 (0·29% C)
No reheating	$\gamma + (\alpha \rightarrow \sigma) + \bar{C}$ *wm*†	$\gamma + (\alpha \rightarrow \sigma) + C$ *wm*	$\gamma + C$ precipitate mainly at grain boundaries *nm*	$\gamma + C$ precipitate mainly at grain boundaries *nm*
4 hr. at 700° C.	$\gamma + (\alpha \rightarrow \sigma) + C$ network *nm*	$\gamma + (\alpha \rightarrow \sigma) + C$ network *nm*	$\gamma + C$ *nm*	$\gamma + C$ Carbide striated *nm*
100 hr. ,,	As 4 hr. *nm*	As 4 hr. *nm*	As 4 hr. *nm*	$\gamma + \bar{\sigma} + C$ *nm*
1000 hr. ,,	$\gamma + \sigma + (\alpha \rightarrow \sigma) + \bar{C}$ *wm*	$\gamma + \sigma + (\alpha \rightarrow \sigma) + \bar{C}$ *wm*	$\gamma + \bar{\sigma} + C$ *nm*	$\gamma + \sigma + C$ *nm*
2000 hr. ,,	$\gamma + \sigma + \overline{(\alpha \rightarrow \sigma)} + \bar{C}$ *wm*	$\gamma + \sigma + \overline{(\alpha \rightarrow \sigma)} + \bar{C}$ *wm*	As 1000 hr. *nm*	As 1000 hr. *nm*
4 hr. at 900° C.	$\gamma + (\alpha \rightarrow \sigma) + \bar{C}$ *nm*	$\gamma + (\alpha \rightarrow \sigma) + \bar{C}$ network *vwm*	$\gamma + C$ *nm*	$\gamma + C$ *nm*
100 hr. ,,	As 4 hr. *nm*	As 4 hr. *nm*	$\gamma + \sigma + C$ *nm*	$\gamma + \bar{\sigma} + C$ *nm*
1000 hr. ,,	$\gamma + \sigma + \overline{(\alpha \rightarrow \sigma)}$ *nm*	$\gamma + \sigma$ *nm*	$\gamma + \sigma + \bar{C}$ *nm*	$\gamma + \sigma + C$ *nm*
2000 hr. ,,	$\gamma + \sigma$ *nm*	$\gamma + \sigma$ *nm*	As 1000 hr. σ more globular *nm*	As 1000 hr. σ more globular *nm*

* γ = Austenite matrix; α = ferrite areas; $(\alpha \rightarrow \sigma)$ = ferrite areas transforming to sigma phase; σ = sigma phase; C = carbide; $\overline{(\alpha \rightarrow \sigma)}$, $\bar{\sigma}$, $\bar{C}$ = small amounts of respective phases

† *sm* = strongly magnetic; *wm* = weakly magnetic; *vwm* = very weakly magnetic; *nm* = non-magnetic

boundaries and possibly along the cleavage planes. After the initial heavy dispersed precipitation of carbide, which commenced earlier in the 0·29% C steel, prolonged heating resulted in sigma formation coincident with an apparent decrease in the amount of carbide. After reheating at 900° C. for 1000 hr. the structures showed more pronounced sigma formation than when reheated at 700° C. for 2000 hr., and showed coalescence of the carbide. After longer periods of time at 900° C., the sigma phase appeared as larger, more uniformly dispersed particles. The remaining carbide was also more evenly dispersed after 2000 hr.

Samples Solution-Treated at 1050° C. (Table I*b* and Fig. 2)

After solution treatment at 1050° C., the 0·06 and 0·09% C steels showed structures consisting of austenite and ferrite exclusively, whilst the 0·19 and 0·29% C steels showed austenite and carbides.

Generally, the mode of sigma-phase formation and carbide precipitation for this series of samples was similar to that of the series solution-treated at 950° C.

Samples Solution-Treated at 1150° C. (Table I*c*)

After solution treatment at 1150° C. the structures of all the steels were generally similar to those treated at 1050° C., although slight increases in the amount of ferrite in the low-carbon range and in the amount of carbide in the high-carbon range were observed.

Reheating the 0·06 and 0·09% C steels at either 700° or 900° C. produced a series of structures similar to the corresponding samples of the lower temperature solution treatments, but the rate of transformation and carbide precipitation seemed to be rather slower, especially in the lower carbon steel. After reheating the 0·19 and 0·29% C steels at either 700° or 900° C. the structures were similar to those of the corresponding samples solution-treated at 1050° C., although the carbide coalescence was a little more advanced with respect to the time of reheating.

Samples Solution-Treated at 1250° C. (Table I*d* and Fig. 3)

Solution treatment at 1250° C. gave coarse-grained structures of austenite and ferrite areas in the 0·06

Table I*b*

MICROSCOPICAL ANALYSIS OF STEELS*

Solution-treated at 1050° C., water-quenched, and reheated

Time and Temp. of Reheating	SG.6679 (0·06% C)	SG.6680 (0·09% C)	SG.6681 (0·19% C)	SG.6682 (0·29% C)
No reheating	$\gamma + \alpha$ *sm*	$\gamma + \alpha + \overline{(\alpha \rightarrow \sigma)}$ *sm*	$\gamma +$ C precipitate mainly at grain boundaries *nm*	$\gamma +$ C *nm*
4 hr. at 700° C.	$\gamma + (\alpha \rightarrow \sigma) +$ C network *nm*	$\gamma + (\alpha \rightarrow \sigma) +$ C network *vwm*	$\gamma +$ C *nm*	$\gamma +$ C *nm*
100 hr. ,,	As 4 hr. *nm*	As 4 hr. *nm*	As 4 hr. *nm*	As 4 hr. *nm*
1000 hr. ,,	$\gamma + \bar{\sigma} + (\alpha \rightarrow \sigma) +$ C *nm*	$\gamma + \sigma + \bar{C}$ *wm*	$\gamma + \sigma +$ C *nm*	$\gamma + \sigma +$ C *nm*
2000 hr. ,,	$\gamma + \sigma + \overline{(\alpha \rightarrow \sigma)} + \bar{C}$ *vwm*	As 1000 hr. *wm*	As 1000 hr. *nm*	As 1000 hr. *nm*
4 hr. at 900° C.	$\gamma + (\alpha \rightarrow \sigma)$ *wm*	$\gamma + (\alpha \rightarrow \sigma) + \bar{C}$ *nm*	$\gamma +$ C *nm*	$\gamma +$ C *nm*
100 hr. ,,	$\gamma + \sigma + (\alpha \rightarrow \sigma)$ *nm*	As 4 hr. *nm*	$\gamma + \sigma +$ C *nm*	$\gamma + \bar{\sigma} +$ C *nm*
1000 hr.	$\gamma + \sigma$ *nm*	$\gamma + \sigma$ *nm*	$\gamma + \sigma + \bar{C}$ *nm*	$\gamma + \sigma +$ C *nm*
2000 hr. ,,	As 1000 hr. *nm*	As 1000 hr. *nm*	As 1000 hr. *nm*	As 1000 hr. *nm*

* For symbols, *see* footnote to Table I*a*

and 0·09% C steels, and completely coarse-grained structures of austenite in the 0·19 and 0·29% C steels, with no evidence of free carbide particles.

The two lower carbon steels showed similar sigma-phase formation with slightly less carbide precipitation than in the samples solution-treated at 1150° C. In the higher carbon steels, reheating at 700° C. gave structures showing dense precipitation of carbide; this persisted in the 0·19% C steel for over 1000 hr. and in the 0·29% C steel for over 2000 hr. The sigma-phase formation was similar to that shown in the samples solution-treated at 1150° C. After reheating at 900° C. the carbide precipitation was similar to that obtained by reheating at 700° C., although coalescence was more pronounced. The rate of sigma-phase formation was generally similar, although more had developed along the cleavage planes than at the lower solution temperatures.

CONFIRMATORY ETCHES

The etch produced by oxalic acid solution has the disadvantage that austenite grain boundaries can be confused with carbide boundary precipitation. Moreover, carbide and the sigma phase in its early stages of formation are not clearly differentiated, especially when the particle size of either is appreciable. The ferrite and fully developed sigma particles may also appear similar.

The following additional methods of etching were used:

(1) Electrolytic etch in a 10% solution of sodium cyanide in water. This etch revealed the carbides before the sigma phase or intermediate aggregate were attacked.

(2) Etch in a solution consisting of 50 parts of hydrochloric acid, 50 parts of water, and 5 parts of nitric acid (*see* Schafmeister[5]). The microstructures obtained were similar in appearance to those illustrated in Figs. 1–3, although the boundaries of carbide and sigma particles were a little more clearly defined. A disadvantage of this reagent is the widely varying times of etching required to give optimum results with different steels or with different heat-treatments for the same steel.

Table Ic

MICROSCOPICAL ANALYSIS OF STEELS*

Solution-treated at 1150° C. for 4 hr., water-quenched, and reheated

Time and Temp. of Reheating	SG.6679 (0·06% C)	SG.6680 (0·09% C)	SG.6681 (0·19% C)	SG.6682 (0·29% C)
No reheating	$\gamma + \alpha$ *sm*	$\gamma + \alpha$ *sm*	$\gamma + C$ precipitate mainly at grain boundaries *nm*	$\gamma + C$ *nm*
4 hr. at 700° C.	$\gamma + (\alpha \rightarrow \sigma) + C$ network *nm*	$\gamma + (\alpha \rightarrow \sigma) + C$ network *nm*	$\gamma + C$ *nm*	$\gamma + C$ *nm*
100 hr. ,,	As 4 hr. *nm*	As 4 hr. *nm*	As 4 hr. *nm*	As 4 hr. *nm*
1000 hr. ,,	$\gamma + (\alpha \rightarrow \sigma) + \bar{C}$ *wm*	$\gamma + \sigma + (\alpha \rightarrow \sigma) + C$ *nm*	$\gamma + \bar{\sigma} + C$ *nm*	$\gamma + \bar{\sigma} + C$ *nm*
2000 hr. ,,	$\gamma + \sigma + (\alpha \rightarrow \sigma) + \bar{C}$ *wm*	As 1000 hr. *nm*	As 1000 hr. *nm*	As 1000 hr. *nm*
4 hr. at 900° C.	$\gamma + (\alpha \rightarrow \sigma)$ *wm*	$\gamma + (\alpha \rightarrow \sigma) + \bar{C}$ network *wm*	$\gamma + C$ *nm*	$\gamma + C$ *nm*
100 hr.	As 4 hr. *nm*	As 4 hr. *nm*	$\gamma + \sigma + C$ *nm*	$\gamma + \sigma + C$ *nm*
1000 hr. ,,	$\gamma + \sigma$ *nm*	$\gamma + \sigma$ *nm*	$\gamma + \sigma + C$ *nm*	$\gamma + \sigma + C$ σ globular *nm*
2000 hr.	As 1000 hr. *nm*	As 1000 hr. *nm*	$\gamma + \sigma + \bar{C}$ σ mainly globular *nm*	As 1000 hr. *nm*

* For symbols, see footnote to Table Ia

(3) Etch in modified concentrated Murakami's solution[6] of 60 ml. of water and 30 g. of potassium hydroxide saturated with potassium ferricyanide.

After immersing the samples for a few seconds in the solution at 80° C., the sigma phase was stained to a colour varying from bronze to light blue, depending on the thickness of the stain film. The carbides were darkened and the ferrite was lightly stained.

The stain-etch given by this solution was found to be limited by the inability of the stained film to be retained on smaller-sized particles of sigma phase. The flaky nature of the film would account for this limitation.

(4) Electrolytic etch in a 10% solution of copper sulphate in 10% sulphuric acid.

The control of current density appeared to be important, and a value between 30 and 100 m.amp./sq. cm. for a time period of 50 sec. was found to be generally satisfactory. Carbides were first darkened, and this was followed by slight darkening of the ferrite; the sigma phase was then outlined, and ferrite–sigma structures were darkened at this later stage. Acid copper sulphate solution overcomes, to some extent, the disadvantages of oxalic acid etch, although its reaction on the carbides is more vigorous, with the result that the other constituents (particularly fully developed sigma) are less clearly defined. This feature becomes more pronounced with increasing carbon content.

(5) Temper-etching[7] in air for 20 min. at a temperature of approximately 650° C.

The temper colours distinguish the various phases; austenite passes through the range first, followed by ferrite and then sigma. Carbides resist the oxidation longest. The heating period of 20 min. was satisfactory, provided that the samples were scrupulously clean before heating. The austenite then appeared blue to purple, ferrite was pale yellow, sigma was orange to bronze, and the carbide remained white. After this treatment any cracks present within the sigma-phase particles were readily seen.

A satisfactory photomicrograph of the temper-etched structure is difficult to obtain by the normal half-tone photographic process, because of its inability to produce shades representative of the range of temper colours. For visual examination, temper-etching gives a very definite contrast between carbide particles and sigma phase, and

Table Id

MICROSCOPICAL ANALYSIS OF STEELS*

Solution-treated at 1250° C. for 4 hr., water-quenched, and reheated

Time and Temp. of Reheating	SG.6679 (0·06% C)	SG.6680 (0·09% C)	SG.6681 (0·19% C)	SG.6682 (0·29% C)
No reheating	$\gamma + \alpha$ *sm*	$\gamma + \alpha$ *sm*	γ *nm*	γ *nm*
4 hr. at 700° C.	$\gamma + (\alpha \rightarrow \sigma) + C$ network *nm*	$\gamma + (\alpha \rightarrow \sigma) + C$ network *vwm*	$\gamma + C$ *nm*	$\gamma + C$ *nm*
100 hr. ,,	As 4 hr. *vwm*	$\gamma + \sigma + (\alpha \rightarrow \sigma) + C$ *nm*	As 4 hr. *nm*	As 4 hr. *nm*
1000 hr. ,,	$\gamma + (\alpha \rightarrow \sigma) + \bar{C}$ *wm*	$\gamma + \sigma + (\alpha \rightarrow \sigma) + \bar{C}$ *nm*	$\gamma + \bar{\sigma} + C$ *nm*	$\gamma + \bar{\sigma} + C$ *nm*
2000 hr. ,,	$\gamma + \sigma + (\alpha \rightarrow \sigma) + \bar{C}$ *wm*	As 1000 hr. *nm*	$\gamma + \sigma + \bar{C}$ *nm*	$\gamma + \sigma + C$ *nm*
4 hr. at 900° C.	$\gamma + (\alpha \rightarrow \sigma)$ *wm*	$\gamma + (\alpha \rightarrow \sigma) + \bar{C}$ network *wm*	$\gamma + C$ *nm*	$\gamma + C$ *nm*
100 hr. ,,	As 4 hr. *nm*	As 4 hr. *nm*	$\gamma + \sigma + C$ *nm*	$\gamma + \sigma + \bar{C}$ *nm*
1000 hr. ,,	$\gamma + \sigma$ *nm*	$\gamma + \sigma$ *nm*	As 100 hr. *nm*	$\gamma + \sigma + \bar{C}$ *nm*
2000 hr. ,,	As 1000 hr. *nm*	As 1000 hr. *nm*	As 1000 hr. *nm*	As 1000 hr. *nm*

* For symbols, *see* footnote to Table Ia

when used in conjunction with magnetic analysis it provides a useful technique for the differentiation between ferrite and sigma phase. Typical results of temper-etching for a 0·19% C steel are shown in Fig. 4.

Although other etches were tried, the solutions (1)–(5) were considered the most useful. No additional information was obtained from certain reagents mentioned by Dulis and Smith.[8]

Magnetic Tests—The arbitrary results obtained on each specimen by a simple magnetic balance are included in Tables I*a–d*.

X-RAY EXAMINATION

The most satisfactory method for the X-ray study of these steels was to examine the carbide and sigma, and in certain cases ferrite, isolated by electrolytic solution in ferric chloride. The residue obtained from each sample was photographed by the Debye-Scherrer powder method, which usually enabled the minor constituents to be readily identified. In a few cases—particularly after the solution treatments—grains of austenite matrix or oxides appeared in the residues.

The samples were examined after being solution-treated for 4 hr. at temperatures of 950–1250° C. and after reheating for 4 hr. and 2000 hr. at temperatures of 700° and 900° C. It seems likely that the solution-treatment temperature of 950° C. was too low for complete solution of the sigma phase, and this theory is supported by the microscopical examination. Nevertheless, the results agree fairly well with those obtained from the steels which were solution-treated at the higher temperatures, particularly in regard to the constituents present after subsequent treatment at 700° and 900° C.

The results of the X-ray examination are summarized in Table II, and are in good agreement with the microscopical work. The following observations may be made:

(1) The ratio of carbide to sigma in the residue increased as the carbon content was raised.

(2) The X-ray photographs of the residues obtained from the two lower carbon steels indicated the presence of sigma after only 4 hr. at either temperature. No sigma was found in the two higher carbon steels after reheating for 4 hr. at either 700° or 900° C., but it is present in reasonable amounts after 2000 hr.

(3) The lower carbon steels have evidently entered the $\alpha + \gamma$ region at the temperatures of solution, whilst the higher carbon steels have probably passed into a homogeneous γ region. Ferrite, if present under such conditions, is usually detected by the residue method, and it will be seen (Table I) that no ferrite was detected microscopically in the two higher carbon alloys.

The question of whether a metastable ferrite forms from austenite at an intermediate stage prior to the formation of sigma has also been considered. Since this ferrite would be less likely to occur in the residues, additional X-ray photographs were taken of appropriate solid specimens of the higher carbon alloys. Under these conditions, any more than a trace of metastable ferrite should have been detected, but none was found.

(4) Particles of γ matrix appeared in the residue either when there was little or no trace of undissolved minor constituents (apart from oxide inclusions) or after the 4-hr. treatment in certain cases where the presence of γ may have been due to uneven composition in the grains accompanying incomplete precipitation.

(5) The carbide constituent in the two lower carbon alloys appeared to have completely dissolved at solution temperatures of 1050°, 1150°, and 1250° C. On the other hand, there was very much more carbide present in the two higher carbon steels, and solution was not complete except at 1250° C. The effect of longer times at the lower solution temperatures has not been studied.

DISCUSSION OF RESULTS

The occurrence of sigma phase in high Cr–Ni steels has been the subject of published work by Guarnieri, Miller, and Vawter,[9] and by Gow and Harder.[12] Guarnieri and co-workers have studied the mechanical properties, particularly those at high temperatures, of a steel containing 25% of Cr, 20% of Ni, and 2% of Si. The variations which they found in the microstructural features of the sigma phase are similar to those described by the present authors.

The results of the microscopical and X-ray work on the 25/15 Cr–Ni steels reported in this paper show that the formation of sigma phase was affected by the presence of carbon. A higher content of carbon rendered the steel more austenitic, but a fully austenitic steel was not free from sigma formation. In this case, sigma appears to have formed directly from austenite or from carbide, since no intermediate metastable alpha phase was detected by microscopical or X-ray examination in these samples. The appearance of the microstructures of the higher carbon steels after short periods of reheating at 700° or 900° C. might imply the presence of such a constituent, but X-ray examination of the solid specimens revealed no trace of the presence of any body-centred cubic constituent.

The Lower Carbon Steels (0·06 and 0·09% C)

The solution treatment at 950° C. may not have been long enough to effect complete solution of carbide or removal of sigma phase. It seems more likely, however, that the temperature was too low, at least for the former process; in addition, the considerable silicon content may have raised the maximum temperature of sigma stability to above 950° C. On the other hand, at 1050° C. both processes go to completion, and the structures show ferrite in an austenite matrix. At the higher solution temperatures of 1150° and 1250° C. there is a slight increase in grain size and in the amount of ferrite.

The subsequent reheating treatment at 700° C. produced a heavy grain-boundary precipitate of carbide, which progressively coalesced and appeared to diminish in amount. Meanwhile, the formation of sigma phase proceeded to what appeared to be completion after 2000 hr., but the transformation became more sluggish as the solution temperature increased. At 900° C. these effects were more rapid, and at

Fig. 1—Effect of reheating at 700° and 900° C. on specimens solution-treated at 950° C. Specimens electrolytically etched in 10% oxalic acid ×860

FIG. 2. Effect of reheating at 700° and 900° C. on specimens solution-treated at 1050° C. Specimens electrolytically etched in 10% oxalic acid. × 800

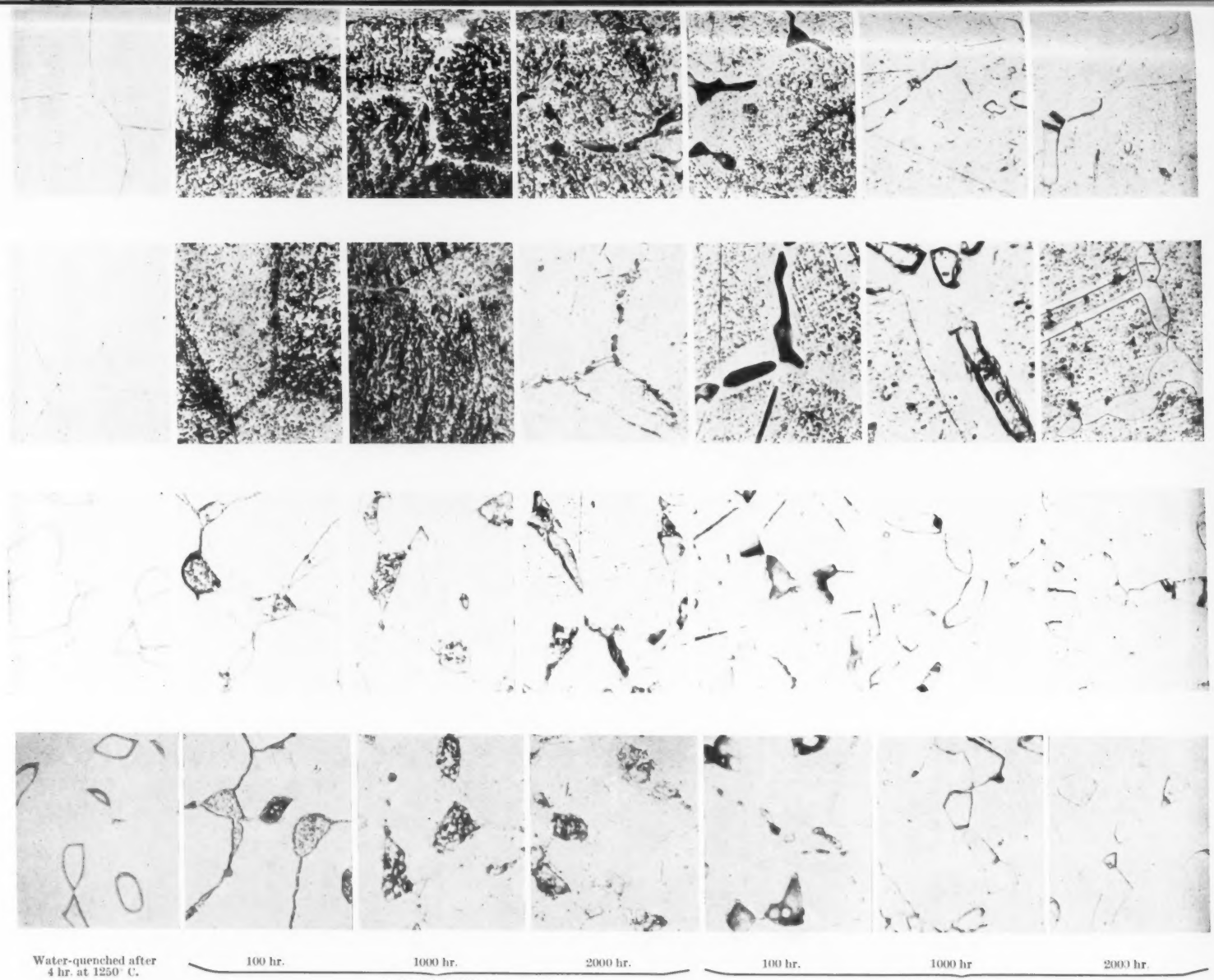

Fig. 3—Effect of reheating at 700° and 900° C. on specimens solution-treated at 1250° C. Specimens electrolytically etched in 10% oxalic acid × 800

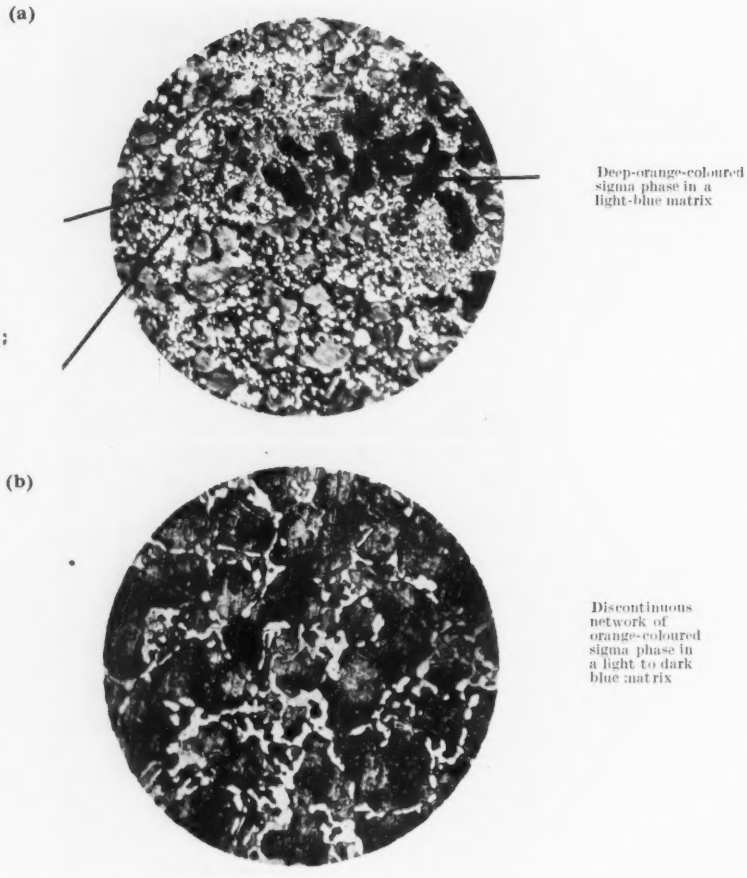
(a)
Orange-coloured sigma phase
and
small white carbide particles in a medium to dark blue matrix
Deep-orange-coloured sigma phase in a light-blue matrix
(b)
Discontinuous network of orange-coloured sigma phase in a light to dark blue matrix

Fig. 4—Temper-etched specimens of a steel of similar composition to *SG*. 6681 after reheating for 1000 hr. at 900° C. following solution-treatments at: (*a*) 1000° C.; (*b*) 1350° C. × 300

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1000 hr. the structures appeared to have reached an equilibrium condition.

The Higher Carbon Steels (0·19 and 0·29% C)

Ferrite was not produced in these steels after the solution treatments. As the solution temperature was increased there was progressive solution of the carbide, until at 1250° C. no free carbide was evident. The increase in grain size with increase in solution-treatment temperature was less pronounced than in the lower carbon steels, although the general grain size was coarse, particularly after treatment at 1250° C. Subsequent reheating at 700° C. resulted in pronounced precipitation of carbide at the grain boundaries and crystal planes and dispersed within the grains, respective amounts being dependent on whether the initial solution-treated structure showed free carbide or complete solution. In the former case the main precipitation was at the grain boundaries and along the crystal planes : in the latter case precipitation was dispersed, although it was slightly more pronounced at the boundaries. With increased time at 700° C. the carbide coalesced and migrated towards the grain boundaries. The development of sigma phase, which occurred only at the grain boundaries and cleavage planes, followed the coalescence of the carbide, and there was an apparent lowering in the amount of carbide present in the areas around the grain boundaries, especially in the vicinity of the sigma-phase particles. Increase in carbon content and in solution temperature resulted in a retardation of the formation and development of the sigma phase.

Constitutional Aspects

The results obtained in both microscopic and X-ray examination may be considered in conjunction with the

Table II

X-RAY ANALYSIS OF RESIDUES : IDENTIFICATION OF PHASES AND RELATIVE AMOUNTS

Heat-Treatment	SG.6679 (0·06% C)	SG.6680 (0·09% C)	SG.6681 (0·19% C)	SG.6682 (0·29% C)
Solution-treated at 950° C.				
No reheating	γ (+ oxides)	σ: large Carbide: small/medium	Carbide*	Carbide
2000 hr. at 700° C.	σ: large Carbide: medium	σ: large Carbide: medium	σ: medium Carbide: large	σ: medium/large Carbide: medium/large
4 hr. at 900° C.		σ: large Carbide: small		
2000 hr. ,,	σ: large Carbide: very small	σ: large Carbide: very small	σ: medium Carbide: large	σ: medium Carbide: large
Solution-treated at 1050° C.				
No reheating	α-Fe (+ oxides)	α-Fe (+ oxides)	Carbide (+ oxides)	Carbide (+ oxides)
4 hr. at 700° C.	σ: very large Carbide: small	σ: medium/large Carbide: medium/large	Carbide (+ γ matrix)	Carbide
2000 hr. ,,	σ: medium/large Carbide: medium/large	σ: large Carbide: medium	σ: medium/large Carbide: large	σ: medium large Carbide: large
4 hr. at 900° C.	σ: very large (oxides and γ)	σ: large + Carbide: small	Carbide	Carbide
2000 hr. ,,	σ: large Carbide: small	σ: large Carbide: medium/small	σ: medium Carbide: large	σ: medium/large Carbide: large
Solution-treated at 1150° C.				
No reheating	α-Fe (+ oxides)	α-Fe (+ oxides)	Carbide: large (+ oxides)	Carbide: large (+ oxides)
4 hr. at 700° C.	σ: medium/large Carbide: medium/large	σ: medium/large – Carbide: medium/large +	Carbide (+ γ)	Carbide (+ γ)
2000 hr. ,,	σ: large – Carbide: medium/large	σ: medium/large Carbide: large	σ: medium Carbide: small (+ γ matrix)	σ: medium/large Carbide: medium/large
4 hr. at 900° C.	σ: large Carbide: medium large/ medium	σ: medium/large Carbide: medium large	Carbide	Carbide
2000 hr. ,,	σ: large Carbide: small	σ: large – Carbide: medium +	σ: medium Carbide: medium/large	σ: large/medium large Carbide: medium +
Solution-treated at 1250° C.				
No reheating	α-Fe (+ oxides)	α-Fe (+ oxides)	γ matrix (+ oxides)	γ matrix (+ oxides)
4 hr. at 700° C.	σ: small Carbide: large	σ: medium Carbide: large	Carbide	Carbide
2000 hr. ,,	σ: large + Carbide: medium/small	σ: large Carbide: medium	σ: large/medium large Carbide: medium +	σ: medium large Carbide: medium large
4 hr. at 900° C.	σ: medium Carbide: large	σ: medium Carbide: large	σ: trace Carbide: very large	σ: medium/small Carbide: large
2000 hr. ,,	σ: very large Carbide: very small	σ: very large Carbide: small	σ: medium large Carbide: medium large	σ: medium Carbide: large

* The constitution of carbide is $(Cr,Fe)_{23}C_6$

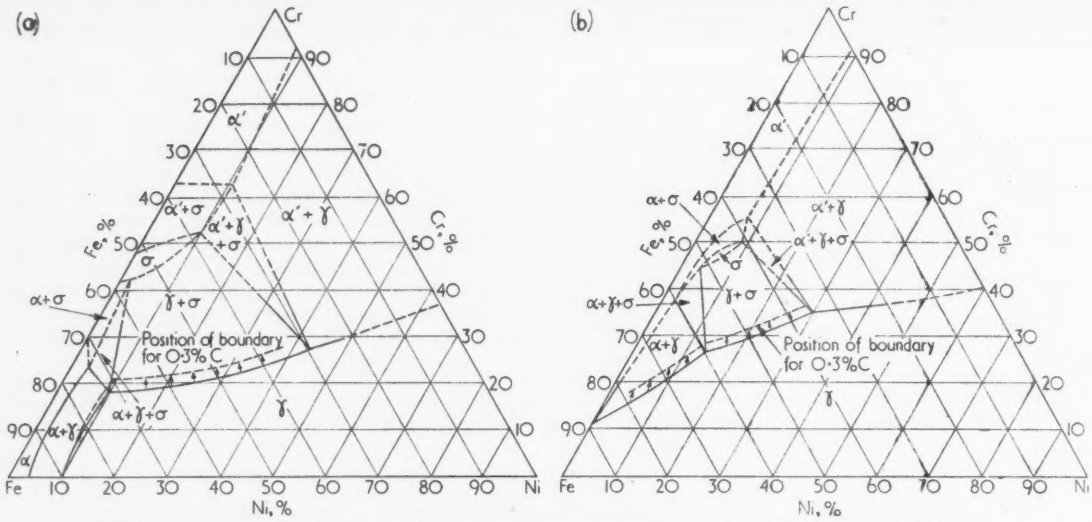

Fig. 5.—Isothermal sections of the Fe–Cr–Ni ternary system. (*a*) At 700° C.; (*b*) at 900° C.

equilibrium relationships for alloys of the approximate composition studied. The equilibrium relationships are not accurately known, even for pure Fe–Cr–Ni alloys, except for the recent work of Rees, Burns, and Cook,[10] whose isothermals at 650° and 800° C. may be taken as a basis for discussion. Figures 5*a* and *b* depict, in the authors' view, the isothermal sections at 700° and 900° C., respectively. The boundaries at 700° C. lie between those at 650° and 800° C., given by the N.P.L. work; the 900° C. isothermal is based on the N.P.L. work and on other data, but is less accurate than the isothermal at 700° C.

The maximum temperature at which the sigma phase exists in the ternary Fe–Cr–Ni system is considerably higher than in the binary system Fe–Cr, in which it is about 810° C. The presence of silicon, even more than nickel, raises this temperature, and it seems probable that, for certain compositions, sigma persists up to temperatures between 900° and 950° C. This conclusion is based on the observations of Schafmeister and Ergang[11]; theirs is the only work in this field, except for that of Rees *et al.*,[10] who investigated silicon-free alloys and the diagrams for the pure binary systems. The alloys studied in the present work have silicon contents markedly higher (*e.g.*, 1% more) than those studied by Schafmeister and Ergang, and the maximum temperature of sigma formation is believed to lie between 950° and 1050° C.

The effect of the relatively high silicon content, as well as the effect of carbon, on the positions of the phase boundaries must be considered, in view of the tendency of silicon to favour sigma formation. The effect of carbon alone is in the reverse direction to the effect of silicon, as is evident from the ready formation of a carbide which is rich in chromium and therefore reduces the chromium content of the matrix. Figure 5 shows the positions of the relevant phase boundaries for 0·3% of carbon combined as $(Cr,Fe)_{23}C_6$ with Cr/Fe = 7/3. Not quite all the carbon may be so combined, but the evidence from the steel containing only 0·06% of C is that a considerable fraction even of this small amount is combined as carbide, which suggests that the amount of residual carbon in solid solution is very small. The intermediate positions for boundaries corresponding to carbon contents lower than 0·3% can readily be interpolated.

Figure 5*a* shows that steels containing about 25% of Cr and 15% of Ni are well within the $\gamma + \sigma$ region at 700° C. At 900° C. (Fig. 5*b*) a pure alloy of this composition lies just outside, even when there is no carbon present. Sigma phase was present in the steels at both temperatures, thus giving evidence of the marked effect of the silicon content. Gow and Harder[12] have suggested that silicon is equivalent to three times its weight of chromium. For similar alloys (23–27% of Cr and 10–13% of Ni) containing about 1% of Si, they stated that steels heated for 48 hr. at 870° C. were completely composed of austenite and carbide (no sigma or ferrite) if (Cr − 16C)/Ni was not greater than 1·7. With a silicon content much greater than 1%, the corresponding ratio would be $\{Cr - 16C + 3(Si - 1)\}/Ni$. The quantity 16C corresponds approximately to a carbide of composition Cr_4C, but a somewhat lower factor would be more correct if the carbide contained iron. Gow and Harder suggested that manganese might also be allowed for by a factor of $\frac{1}{3}$; although it is not certain how accurate this value is, it is sufficient for semi-quantitative considerations of this nature.

Values of this empirical ratio and of 'corrected' Cr and Ni contents for the four alloys investigated are as follows:

Quantity	SG.6679	SG.6680	SG.6681	SG.6682
Carbon content, %	0·06	0·09	0·19	0·29
$\frac{Cr - 16C + 3(Si - 1)}{Ni}$	1·73	1·73	1·61	1·50
'Corrected' Cr content,* %	29·61	30·01	29·28	27·87
'Corrected' Ni content,* %	15·44	15·60	15·89	16·13

* Based on same factors as for Si and Mn, but C allowed for as $(Cr,Fe)_{23}C_6$

The ratio suggested by Gow and Harder would imply that there should have been sigma in the first two steels but not in the second two. In fact, sigma occurs in all four steels, although a period of only 4 hr. at temperatures of 700° and 900° C. is insufficient to ensure its detection in the two high-carbon steels in which it appears less readily. The samples examined by Gow and Harder may not have reached equilibrium, even after 48 hr. at 870° C., or sigma in small amounts may not have been detected in the presence of carbide. The ratio, however, is greater than 1·7 for the two steels which were partly ferritic after solution treatment and in which sigma readily formed from this ferrite. The ratio is lower than 1·7 for the higher carbon alloys, in which there was no ferrite present at the solution temperatures but in which sigma did form at lower temperatures within the austenite matrix and at grain boundaries, and was not so easily distinguishable microscopically from carbide. Thus, a ratio such as Gow and Harder suggested may have a significance in relation to the condition of a steel after solution treatment and hence in relation to the mode of formation of the sigma phase, but it does not divide sigma-forming alloys from sigma-free alloys.

Further investigation would be required to test the accuracy of the assumptions made concerning the equivalent effects of silicon and other elements. However, the values of 'corrected' Cr and Ni give compositions which would be in the $\gamma + \sigma$ region in Fig. 5, in accordance with the experimental evidence. If it is desired to avoid the ferritic condition at the higher temperatures, the results suggest that the dividing line in composition must be placed between the alloys SG.6680 and SG.6681. Judging by the amounts of ferrite in SG.6680, the alloy SG.6681 has probably only just avoided the ferritic condition.

CONCLUSIONS

(1) The effect of increasing the carbon content of 25/15 Cr–Ni steel has been to decrease the amount of ferrite in the structures obtained by solution treatment at temperatures between 950° and 1250° C., inclusive, after 4 hr. soak. The ultimate result of this increase in carbon has been to produce completely austenitic structures at the highest temperature, 1250° C. The structures obtained in the steels after solution treatment were as follows:

(i) *Austenite and ferrite* in steels containing 0·06 and 0·09% of carbon, solution-treated at 1050–1250° C.
(ii) *Austenite and carbide* in steels containing 0·19 and 0·29% of carbon, solution-treated at 950–1150° C.
(iii) *Austenite* in steels containing 0·19 and 0·29% of carbon, solution-treated at 1250° C.

(2) Sigma phase is formed in all three of these structures after prolonged reheating at 700° and 900° C. With increase in carbon content and increase in solution temperatures, the beginning and development of the sigma-phase formation is generally slower.

(3) The mode of occurrence of the sigma phase, which develops with prolonged reheating at 700° and 900° C., is governed by the structures of the steel resulting from the initial solution treatment.

(4) The formation of sigma phase in the duplex austenite–ferrite structures takes place in the ferrite regions, and the rate of formation appears to be relatively rapid. This type of formation is probably caused by the higher chromium content of the ferrite, although while equilibrium conditions are being attained, diffusion of elements occurs between the alpha, gamma, and sigma phases.

(5) The formations of sigma phase within an austenite or austenite–carbide structure are essentially similar, owing to the primary precipitation of carbide on reheating at 700° or 900° C. Goldschmidt[13] has suggested the possible internal decarburization of the carbide $M_{23}C_6$ to form sigma phase and ferrite. This suggestion can be developed to explain a possible mechanism of sigma formation in alloys which do not contain the alpha phase after quenching from a high temperature. The following hypothesis is postulated:

On initial carbide precipitation from the austenite matrix, an adjustment of composition of the austenite takes place, producing an impoverishment in chromium and carbon and a consequent increase in the nickel content. This reduces the liability to spontaneous precipitation of sigma phase. Migration and coalescence of carbide occurs towards the grain boundaries and crystallographic planes, and when critical size is attained or other unknown critical conditions are favourable, the carbide breaks down to form sigma phase. The liberation of some of the chromium and of the carbon from the carbide changing to sigma will enrich these elements in the adjacent austenite, thus increasing the tendency to sigma-phase formation. Meanwhile, the migration of carbide is proceeding by diffusion from the inside of the grains towards the boundaries, thus still further increasing the tendency to sigma-phase formation. These processes continue until the adjusted composition of the austenite (*i.e.*, increased nickel content) produces stability. This hypothesis is put forward only tentatively; it is by no means clear how the observed facts ought to be interpreted.

The parallel hypothesis featuring the fine precipitation of the metastable alpha phase, which could transform to sigma phase, has not been overlooked. However, the experiments on these steels have failed, so far, to indicate the presence of an intermediate alpha phase, although the dark etching boundary constituent, evident in the high-carbon steels reheated at 700° C. for up to 2000 hr. and at 900° C. for up to 100 hr., may be a ferrite–sigma aggregate.

(6) Sigma phase, carbide, and ferrite have been identified by X-rays in residues from electrolytic solutions of selected samples. The results are in general agreement with those of the microscopical observations.

(7) The constitution of the alloys examined has been discussed in relation to available equilibrium data, and the effects of carbon and silicon have been considered from this viewpoint. The subject requires further study, and it is hoped that further research and accumulating experience on commercial alloys will eventually enable a fair estimate of the effect of minor elements to be made.

Acknowledgments

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Correspondence on the Paper—

CORROSION BY RETAINED TREATMENT CHEMICALS ON PHOSPHATED STEEL SURFACES*

By S. G. Clarke and E. E. Longhurst

Mr. **R. J. Brown** (Morris Motors Ltd.) wrote : The title of this paper is rather unfortunate, since the work described relates to treatment chemicals retained in overlapping joints in the metal, whereas corrosion can also be caused by treatment chemicals retained in the phosphate film on the steel surface itself. Corrosion of this type, shown in Fig. *A*, is popularly termed 'snail-trail' corrosion to distinguish it from filiform corrosion (Fig. *B*), which occurs under certain conditions with painted steel that has not been pretreated by one of the phosphate processes. Snail-trail corrosion has only been observed, as far as is known, on steel assemblies that have been treated by rotation of the assembly through a continuous phosphating plant. This type of corrosion is caused by an accumulation of soluble salts at the fringe areas of draining trails as the hot assembly leaves the chromic rinse. Fortunately, this type of corrosion has now been eliminated.

Contamination of the phosphate film itself by treatment chemicals should not be ignored as a possible cause of corrosion of phosphated steel surfaces in service, particularly under conditions of high humidity.

Fig. A—Snail-trail corrosion

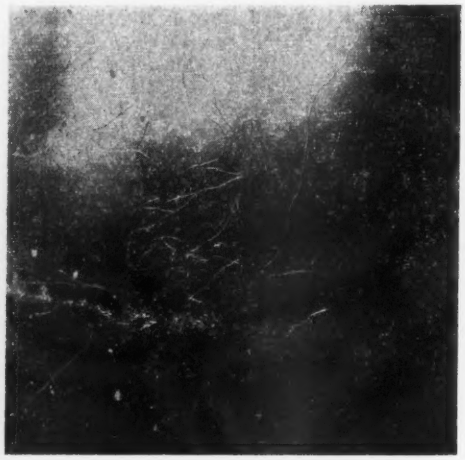

Fig. B—Filiform corrosion

AUTHORS' REPLY

Dr. **Clarke** and Dr. **Longhurst** wrote in reply : The effects at creviced joints were certainly given prominence in our paper, but the paper also directs attention to corrosion on surfaces without crevices if certain phosphating processes are used and if the solution is not properly washed off. The snail-trail corrosion shown in Fig. *A* is of considerable interest and practical importance in this connection, and although the full details of the phosphating process used are not given, the result, as Mr. Brown points out, represents the ill-effect of a limited amount of harmful material when concentrated locally by drainage and drying conditions peculiar to a particular set of processing conditions. From the photograph, the trails appear to be made up of small blisters in the paint film, but it is not apparent to what extent rusting had commenced under the blisters. The degree of rusting, if any, might be an indication of carry-over of phosphating solution into the chromic rinse. This example, although not so bad as we have seen in some practical cases resulting from neglect of rinsing, is indicative of the care that is necessary in planning adequate washing procedures.

J. Iron Steel Inst., 1952, vol. 170, pp. 15–18.

Heterogeneous Nucleation of Graphite in Hypo-Eutectoid Steels

By W. E. Dennis

SYNOPSIS

To understand the mechanism by which deoxidation with aluminium, in excess of ½ lb./ton, accelerates the graphitization of hypo-eutectoid steels at elevated subcritical temperatures, the effect of different atmospheres during graphitization and of prior heat-treatment in the austenitic range, upon the reaction rate, was investigated. It was found that the rapid graphitization of these steels is caused by the heterogeneous nucleation of graphite by alumina dispersions that are formed by internal oxidation during graphitization. The rate of nucleation seems to be dependent on the extent to which the residual aluminium is segregated prior to graphitization.

THE dissociation of cementite into ferrite and graphite was known to be thermodynamically possible, but it was thought improbable that it would occur to a measurable extent during the normal life of hypo-eutectoid steels, even at elevated subcritical temperatures. The possibility that the rate of reaction might be greatly accelerated by the presence of other elements, though acknowledged, was not given serious consideration until 1943, when the failure of a high-temperature steam pipe at the Springdale Generating Station in the U.S.A., was found to be caused by localized graphitization.

Although more than 40 investigations into the graphitization of low-carbon low-alloy steels were subsequently reported, many of the observations were contradictory, and few of the trends inferred had been definitely established. Substantial evidence had, however, accumulated in support of the following points:

(i) Deoxidation by quantities of aluminium in excess of ½ lb./ton progressively increases the rate at which hypo-eutectoid steels graphitize at elevated subcritical temperatures[1–10]

(ii) The rate of graphitization increases with temperature within the subcritical range[9–12]

(iii) Normalizing from high temperatures reduces the tendency of these steels to graphitize[10, 13, 14]

(iv) In welded specimens graphite forms preferentially in the region of the Ac_1 isotherm, forming 'eyebrows' corresponding to the individual weld passes.[1, 4, 10, 13, 15]

Two questions of fundamental significance remained unanswered: firstly, whether it is the residual or the oxidized aluminium in these steels which accelerates their graphitization; and secondly, whether the graphitization is retarded by increasing the grain size or by some other process occurring during high-temperature normalizing. The present investigation was designed to answer these two questions.

GENERAL PROCEDURE

Heats of steel made in a laboratory induction furnace were killed with 4·5 lb./ton of aluminium to ensure a high susceptibility to graphitization. The analyses of these steels (which differed greatly in their tendencies to graphitize, in the as-received condition) fell within the following limits:

Carbon	0·20–0·22%
Silicon	0·23–0·25%
Manganese	0·50–0·60%
Phosphorus	0·015–0·020%
Sulphur	0·020–0·022%
Residual Aluminium	0·14–0·16%

Each steel was held for 15 min. at 1250° C. at the end of fabrication, to produce a coarse austenitic grain size.

Whenever the graphitization of specimens under different conditions or after different pretreatments was to be compared, the specimens were taken from the same ingot, which had been rolled to a ½-in. dia. bar, to eliminate the effect of the composition and past history of the as-received material on the relative rates of graphitization. The specimens, cylindrical in shape and about 20 g. in weight, were graphitized at 600 ± 5° C. and were then cut into three portions, the centre slice for microscopic examination and the two remaining parts (which were freed from scale and from decarburized layers by grinding) for chemical analyses. Thus every specimen was analysed in duplicate by the combustion method, which gave a consistency of ± 0·004% of graphite. The average number of nodules per cu. in. developed in various specimens was obtained by examination of the centre slices across a diameter at 27 equispaced points and counting the nodules, at a magnification of × 250, on a ground-glass screen. These nodule-number estimates were reproducible to within $\pm 0{\cdot}5 \times 10^6$ nodules per cu. in.

In the several instances when it was required to heat specimens in a vacuum, they were sealed in close-fitting silica phials because earlier experiments had indicated that continuous evacuation at high temperatures removed aluminium from the steel. To prevent appreciable oxygen diffusion into these phials even at 600° C., it was found necessary to use a transparent grade of silica.[16]

THE EFFECT OF ALUMINIUM

The frequently reported observations that deoxidation with aluminium accelerated graphitization only when the quantity used was in excess of a certain minimum, and that further additions progressively increase the effect, suggested that the phenomenon

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Mr. Dennis is now working with the Nuffield Research Group in Extraction Metallurgy at the Royal School of Mines.

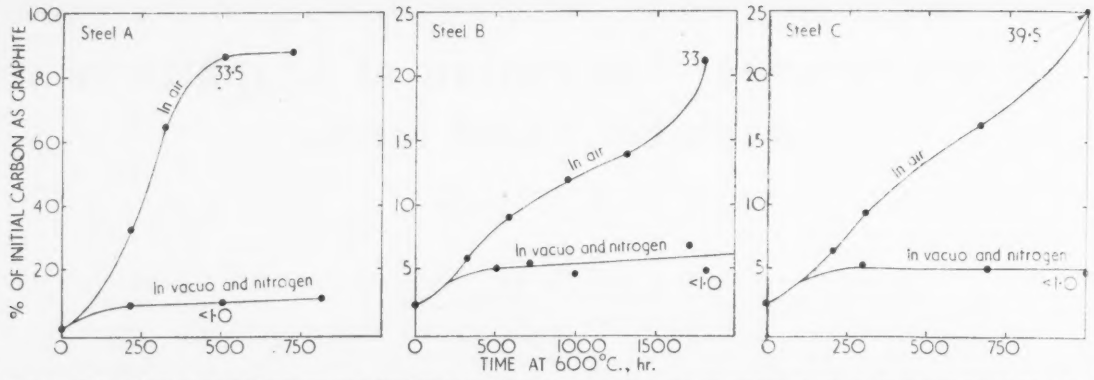


Fig. 1—The effect of excluding oxygen during graphitization on the rates at which steels *A*, *B*, and *C* graphitize in the as-received condition at 600° C. (The figures on the curves, × 10⁶, are the numbers of nodules produced per cu. in.)

was caused by the residual unoxidized aluminium. Nevertheless, graphitization involves the solution of cementite, the diffusion of carbon, and the precipitation of graphite, and it seemed most unlikely that residual aluminium in solid solution could appreciably increase the rate of any of these processes.

These two conflicting conclusions would be wholly reconciled if the accelerated graphitization depended on the precipitation of finely dispersed alumina by internal oxidation of the steel during graphitization. Internal oxidation[17, 18] during graphitization did not seem improbable, and there was a possibility that a submicroscopic dispersion of alumina, so formed, might greatly increase the rate of nucleation of graphite.[19]

Experimental Procedure and Results

To test the above suggestion, specimens from steels *A*, *B*, and *C* were graphitized in air, *in vacuo*, and in purified nitrogen. Figure 1 shows that both *in vacuo* and in nitrogen the rate of graphitization approaches asymptotically a comparatively small value early in the process and that the number of nodules developed is also greatly reduced by the exclusion of oxygen. Microscopic examination and calculation reveal that the nodules are several times larger in size than those found in the specimens graphitized in air. Thus the exclusion of oxygen during the graphitization of these steels seems to reduce the number of nuclei upon which graphite can precipitate and in so doing increases the rate of growth of those nodules that do develop.

As a further test, the specimen size was reduced to discover whether the period of time required for internal oxidation to affect the whole of a specimen would thus be shortened, and so increase the maximum rate of graphitization. Figure 2 shows that a 37% reduction in diameter almost doubled the maximum rate, by increasing the average rate of nucleation.

The distribution of nodules across the diameter of

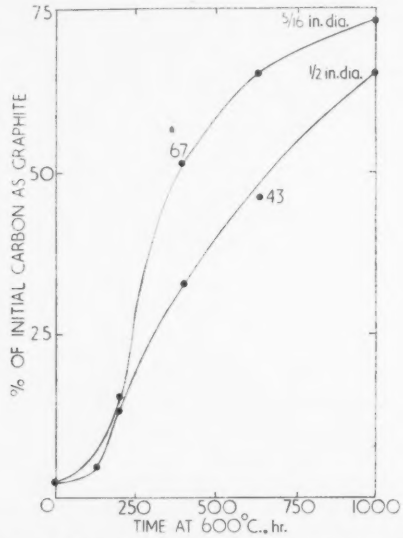


Fig. 2—The effect of reducing the diameter of specimens of steel *D* in the as-received condition, from ½ in. to $\frac{5}{16}$ in., on the rate at which they graphitize in air at 600° C.

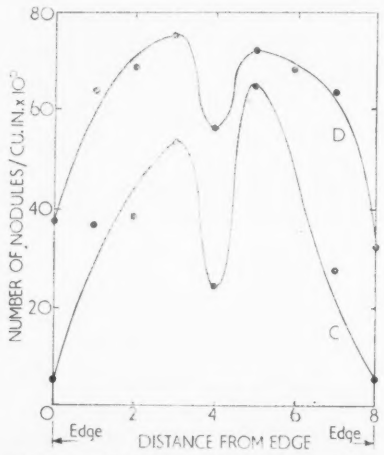


Fig. 3—Characteristic distribution of graphite nodules for a $\frac{5}{16}$-in. dia. specimen of steel *D* that was 50% graphitized after 500 hr. in air at 600° C., and for a ½-in. dia. specimen of steel *C* that was 25% graphitized after 1000 hr. in air at 600° C. (Each increment on horizontal scale is equal to $\frac{1}{8}$ of specimen diameter)

the specimens graphitized in air (*see* Fig. 3) was always of the form observed in the studies of internal oxidation which have been reported.[17, 18] In the present instance the distribution of the alumina, which provided the nucleation for rapid graphitization, was presumably caused by the diffusion of aluminium towards the surface and of oxygen towards the centre of the specimen. In specimens graphitized in an oxygen-free atmosphere the few nodules developed had an apparently random distribution.

Discussion of Results

The results indicate that deoxidation with excessive amounts of aluminium accelerates the graphitization of hypo-eutectoid steels as follows :

(1) It provides a small amount of nucleation by the precipitation of an alumina dispersion during cooling after solidification.[20] During heating at elevated subcritical temperatures with the exclusion of oxygen, this ' primary dispersion ' nucleates a limited number of graphite nodules, which grow rapidly as a result of the lack of competition.

(2) If oxygen is allowed access to the metal surface during graphitization, it diffuses and reacts with the residual aluminium in the steel, causing a ' secondary dispersion ' of alumina which is some 30 times more effective in nucleating graphite than is the ' primary dispersion.'

It is thus the aluminium in excess of that required for deoxidation of the steel which causes accelerated graphitization ; this only occurs when oxidation in the solid state has formed dispersions of alumina which, when situated at the ferrite grain boundaries, provide nuclei for the precipitation of graphite in the supersaturated solid solution.

EFFECT OF HIGH-TEMPERATURE PRETREATMENT

Experimental Procedure and Results

To ascertain whether the heating of fine-grained specimens, at temperatures in the region of 1250° C., prior to graphitization reduces their susceptibility to graphitization, as a result of grain growth or of some other process occurring at these high temperatures, all the steels used were annealed for 15 min. at 1250° C. at the end of fabrication. This eliminated grain size as a variable, because on reheating an as-received specimen to this temperature no appreciable increase in grain size would result (during 15 min. at 1250° C. grain growth in these steels reaches an asymptotic size). Comparison of the graphitization of specimens in the as-received condition with that of specimens heated at 1250° C. for 1 hr., and air-cooled prior to graphitization, showed that some process other than grain growth occurs during 1 hr. at 1250° C. and effects a reduction of almost 50% in the maximum rate of graphitization by reducing the rate at which nucleation occurs (*see* Fig. 4*a*). By microscopic observation it was also found that, for all the treatments being considered, alterations in graphitization rates appeared to result from changes in the rate of nucleation of nodules.

To ascertain whether the observed effect of the 1250° C. treatment was caused only by oxidation, the experiment was repeated with specimens sealed in evacuated silica phials during the treatment.

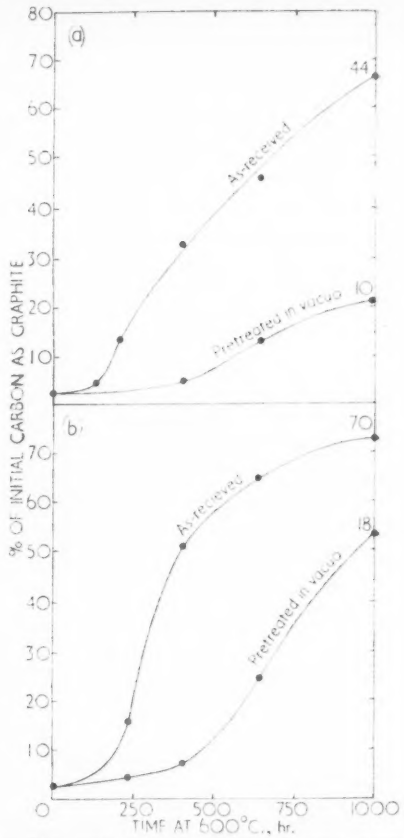


Fig. 4—The rate of graphitization and number of nodules developed after 1000 hr. in air at 600° C. for: (*a*) ½-in. dia. specimens of steel *D* in the as-received condition, and after pretreatment in air at 1250° C. for 1 hr. followed by air-cooling; (*b*) $\frac{5}{16}$-in. dia. specimens of steel *D* in the as-received condition and after pretreatment *in vacuo*, at 1250° C. for 1 hr. followed by air-cooling. (By drawing tangents the reduction in maximum rate effected by the 1250° C. treatment, in air and *in vacuo*, is found to be the same, *i.e.*, 0·0075% of total carbon per hour)

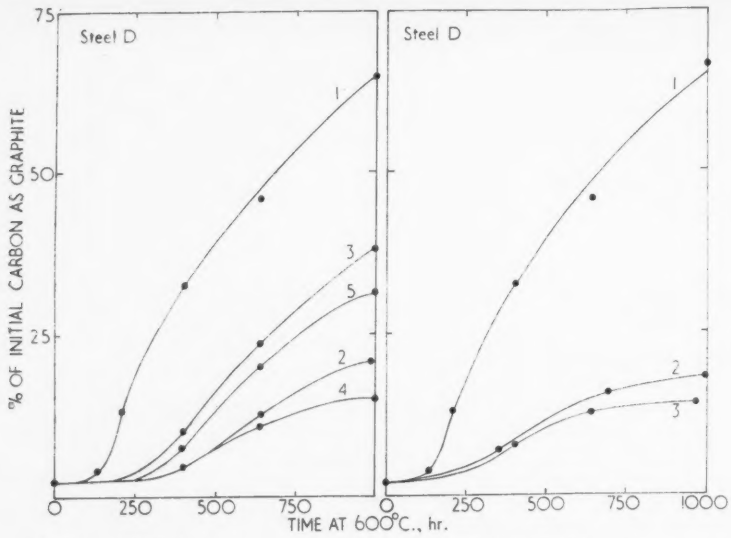
Figure 4*b* shows that oxidation plays only a small part in producing the observed effect.

To define the process that occurs during the 1-hr. treatment at 1250° C. the following variables were investigated : (1) Rate of cooling after treatment ; (2) duration of the treatment, and (3) the temperature of the treatment. The results of this investigation, shown in Fig. 5, give rise to the following conclusions :

(1) By reducing the rate of cooling (in the austenitic range only, to avoid structural changes), the effect of the 1250° C. treatment is reduced (curves 2 and 3). This indicates that the process involved is reversible.

(2) By increasing the time at temperature, the effect of the treatment is increased (curve 4). This indicates that the process involved requires more than 1 hr. to go to completion at 1250° C.

(3) By reducing the temperature, the effect of the treatment is reduced (curve 5). This indicates



Curve 1—As received
Curve 2—Air-cooled after 1 hr. at 1250° C.
Curve 3—Cooled at 7° C./min. to 900° C. after 1 hr. at 1250° C., and then air-cooled
Curve 4—Air-cooled after 2 hr. at 1250° C.
Curve 5—Air-cooled after 1 hr. at 1200° C.

Fig. 5—The effect of time, temperature, and rate of cooling, during the high-temperature pretreatment, on the as-received rate of graphitization at 600° C.

Curve 1—As received
Curve 2—Heated for 1 hr. at 900° C.
Curve 3—Heated for 1 hr. at 950° C.

Fig. 6—The effect on the as-received rate of graphitization of heating specimens of steel *D* at different temperatures and then air-cooling

that the process involved is favoured by high temperatures.

Discussion of Results

These results suggest that high-temperature pretreatment reduces the rate of nucleation in these steels as follows :

(1) In the as-received condition a positive segregation of aluminium exists at the austenitic grain boundaries—a legacy of differential freezing—which is reduced but not removed during fabrication.

(2) Heating at 1250° C. reduces this favourable segregation by homogenization.

(3) Grain-boundary adsorption forces increase with decreasing temperature and may therefore cause some reversion during slow cooling.[21]

It is thus proposed that high-temperature pretreatments retard graphitization by promoting the diffusion of aluminium from regions of high concentration, thereby reducing the rate at which the nucleating clusters of alumina can later be formed by internal oxidation during graphitization.

This proposition is consistent with the findings of Dorn and Harder[22] who have investigated the effect of heat-treatment in the austenitic range on the relation between the grain boundaries and adsorbed aluminium. Their work indicates that reheating these coarse-grained steels just above the upper critical temperature will reduce any existing segregation by recrystallization and re-adsorption. Accordingly, pretreating steels at temperatures low in the austenitic range should severely reduce their rate of nucleation, and if their susceptibility to graphitization were plotted against pretreatment temperatures over the range 900° to 1250° C., a maximum should be incurred at the temperature at which the net effect of the high-temperature (homogenization) process and the low-temperature (redistribution) process is at a minimum. Figures 6 and 7 show that both these conditions are fulfilled.

As the steels used for this investigation were almost identical in chemical composition, the large observed differences between their as-received rates of graphitization must be caused by the differences in their physical history producing different amounts of aluminium segregation. Whilst segregation of

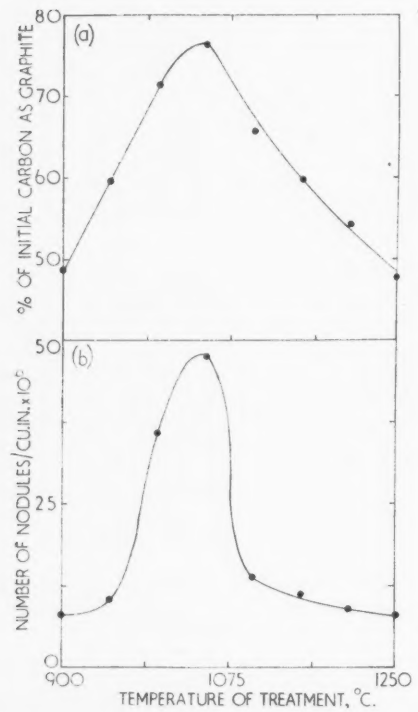


Fig. 7—The effect of preheating steel *A* for 1 hr. followed by air-cooling at different temperatures in the austenitic range, upon: (*a*) The extent to which it graphitizes; (*b*) number of nodules developed during 400 hr. at 600° C.

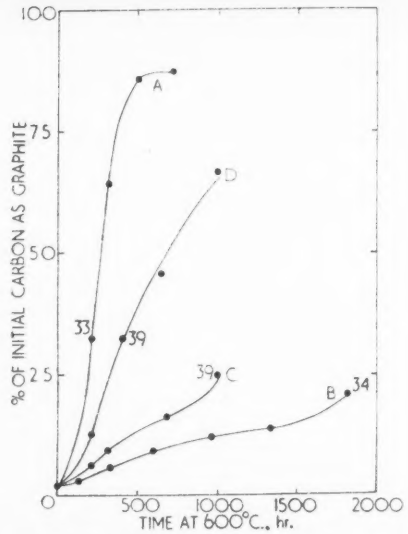


Fig. 8—Rates of graphitization of steels *A*, *B*, *C*, and *D* in the as-received condition, at 600° C. (The figures on the curves, × 10⁶, are the numbers of nodules produced per cu. in.)

aluminium may facilitate the rapid formation of alumina clusters during graphitization and thus accelerate the nucleation rate, it cannot significantly alter the total amount of alumina that can ultimately be formed. Thus, for these steels, the capacity to nucleate should be similar and should be independent of the time required for nucleation to occur. Although, because very long periods of time would have been required, none of these steels were completely graphitized, it appears from Fig. 8 that for all these steels similar amounts of graphitization and nucleation would ultimately have occurred.

CONCLUSIONS

Accelerated graphitization in low-carbon steels deoxidized with excessive amounts of aluminium results from the heterogeneous nucleation of graphite by dispersions of alumina formed in the solid state. The 'secondary dispersion,' formed by internal oxidation of the steel during graphitization, is about 30 times more effective than the 'primary dispersion,' formed during the cooling of the steel, in nucleating graphite. The catalysing effect of foreign particles on nucleation is now fully understood qualitatively, and is recognized in almost every aspect of metallurgical science,[19] but a quantitative description of the process would only be possible if the coherency strains, and interfacial energies with the nucleating particles, could be evaluated. The various rate curves obtained during this investigation were in all cases typical of a nucleation and growth process. Graphite nodules are found exclusively in the ferritic grain boundaries, where diffusion of oxygen should most readily occur.

The effects of pretreatment in the austenitic range upon the graphitization rates of these steels are related to the extent to which the residual aluminium is segregated at the austenitic grain boundaries, this segregation determining the rate at which the nucleating dispersion can be formed by internal oxidation during graphitization. A proper understanding of the 'austenitic segregation effect' requires a knowledge of its relation to the ferritic grain boundaries.

It is suggested that the observed formation of chain graphite in welded specimens along the Ac_1 isotherm results from the segregation of aluminium which must occur, it being some 30 times more soluble in ferrite than in austenite at that temperature.

Acknowledgments

The author acknowledges his indebtedness to his supervisor, Mr. C. R. Tottle, King's College, Newcastle, for the important part which he played in carrying out this work, and for permission to publish this paper. Thanks are also due to his colleagues for helpful discussions.

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Thermodynamic Calculation of Slag Equilibria

By H. Flood, Dr. Ing., and K. Grjotheim

SYNOPSIS

The equilibrium constant of reactions in molten slags, expressed in terms of ion concentrations, is shown to be frequently influenced by concentrations that do not enter into the formal equilibrium equation. An equilibrium between cations only, such as

$$\underline{Mn} + Fe^{++} = \underline{Fe} + Mn^{++}$$

is influenced by the anions present ; similarly, an equilibrium between anions only, such as

$$\underline{2P} + \underline{5O} + 3O^{--} = 2PO_4^{3-}$$

is strongly influenced by the cations present.

A simple thermodynamic relation is derived between the equilibrium constant and the concentrations of ions not entering into the equilibrium equation. The equilibrium constant of the phosphorus equilibrium is expressed to a first approximation as

$$\log K' = N_{Ca^{++}} \log K'_{Ca} + N_{Fe^{++}} \log K'_{Fe} + N_{Mg^{++}} \log K'_{Mg} + \ldots\ldots$$

where $N_{Ca^{++}}$ etc. are the cation fractions in the melt and K'_{Ca} etc. are the equilibrium constants in melts in which only the cation indicated is present. This equation is applied to the following steelmaking equilibria and is tested by means of the experimental results of Winkler and Chipman :

$$\underline{O} + S^{--} = \underline{S} + O^{--}$$

$$\underline{Mn} + Fe^{++} = \underline{Fe} + Mn^{++}$$

$$\underline{2P} + \underline{5O} + 3O^{--} = 2PO_4^{3-}$$

In recent years, equilibria involving fused slags have been the subject of many investigations, both theoretical and experimental, because of their great importance in process metallurgy. The ionic model of fused slags and its statistical treatment are given special importance by Herasymenko,[1] Temkin,[2] and Esin.[3] Considerable difficulties remain, however, in the calculation of slag equilibria, even with these new concepts.

If the fused slag is considered as a mixture of cations (Fe^{++}, Ca^{++}, Mg^{++}, Mn^{++}, etc.) and anions (SiO_4^{4-}, O^{--}, PO_4^{3-}, etc.), it must be remembered that these are very different in respect of size, electrical charge and polarizability. The distribution of the ions in the fused slag, therefore, will probably deviate appreciably from a statistically normal distribution of an ideal mixture of fused salts (*i.e.*, a random distribution of ions with electrical charge of the same sign, independent of the distribution of the ions of opposite sign). In slag containing Fe^{++}, Ca^{++}, O^{--}, SiO_4^{4-}, for example, Esin[3] has shown that there is a preferred Fe^{++}/O^{--} orientation, because the interaction between this pair of ions caused by polarization is stronger than between any other pair. This is shown by the tendency of the slag to split into the separate phases FeO and Ca_2SiO_4—a tendency which greatly complicates the theoretical treatment of the redox equilibria involving FeO. The influence on slag equilibria is, however, much less when only ions of the same electrical sign are involved, as for example :

$$O^{--} + \underline{S} = S^{--} + \underline{O}$$

$$Mn^{++} + \underline{Fe} = Fe^{++} + \underline{Mn}$$

$$\underline{2P} + \underline{5O} + 3O^{--} = 2PO_4^{3-}.$$

In such cases, an equation connecting the equilibrium constant with the composition of the slag (*i.e.* the other ionic concentrations) can be derived by simple thermodynamic reasoning. This has already been done,[4] but as the paper is not readily available the derivations will be recapitulated here, before the equation is tested by application to measured equilibria.

THEORETICAL TREATMENT

Consider a fused salt melt of $A^{(+)}$, $B^{(+)}$ . . .cations* with ionic fractions :

$$N_{A^{(+)}} = \frac{n_{A^{(+)}}}{n_{A^{(+)}} + n_{B^{(+)}} + \ldots.} = \frac{n_{A^{(+)}}}{\Sigma n_{\text{cations}}} \text{ etc.}$$

and $X^{(-)}$, $Y^{(-)}$ anions with ionic fractions :

$$N_{X^{(-)}} = \frac{n_{X^{(-)}}}{n_{X^{(-)}} + n_{Y^{(-)}} + \ldots.} = \frac{n_{X^{(-)}}}{\Sigma n_{\text{anions}}},$$

where $n_{X^{(-)}}$ is the total number of $X^{(-)}$ cations and Σn_{anions} is the total number of anions (*cf.* Temkin[2]). To simplify the derivation, reduce the number of cations and anions to two : $A^{(+)}$, $B^{(+)}$, $X^{(-)}$, $Y^{(-)}$. Let this fused salt be involved in an equilibrium of the type :

$$X^{(-)} + \underline{P} = Y^{(-)} + \underline{Q} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

which can be represented concisely as

$$X^{(-)} = Y^{(-)}.$$

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* The brackets indicate that the electrical charge of the ions may vary.

Table I

SYMBOLS AND SUBSCRIPTS OF PRIMARY MIXTURES

Mixture	Components	System	Subscripts
1	NaCl + NaBr	Na(Cl, Br)	(Na)Cl, (Na)Br
2	KCl + KBr	K(Cl, Br)	(K)Cl, (K)Br
3	NaCl + KCl	(Na, K)Cl	Na(Cl), K(Cl)
4	NaBr + KBr	(Na, K)Br	Na(Br), K(Br)
5	(Na, K)Cl + (Na, K)Br	(Na, K)(Cl, Br)	(Na, K)Cl, (Na, K)Br

For example :
anion equilibria :

$$O^{--} + \underline{S} = S^{--} + O$$

and cation equilibria :

$$Mn^{++} + \underline{Fe} = Fe^{++} + \underline{Mn}.$$

The equilibrium is established in a slag melt containing the mixture (A, B) of the cations $A^{(+)}$ and $B^{(+)}$, with ionic fractions $N_{A^{(+)}}$ and $N_{B^{(+)}}$, together with the mixture (X, Y) of the anions $X^{(-)}$ and $Y^{(-)}$. The ratio $A^{(+)} : B^{(+)} = N_{A^{(+)}} : N_{B^{(+)}}$ is an independent variable, whereas the ratio $X^{(-)} : Y^{(-)}$ must always correspond to the value given by the equilibrium (1).

$$\frac{N_{X^{(-)}}}{N_{Y^{(-)}}} = \frac{1}{K_{(1)}} \cdot \frac{[Q]}{[P]} f(\gamma)$$

where $f(\gamma)$ is the activity coefficient term and $K_{(1)}$ is the equilibrium constant of equilibrium (1).

In accordance with convention, the activity a and the activity coefficient γ are defined by the chemical potential :

$$\mu_i = \mu_i^\circ + R'T \log a_i = \mu_i^\circ + R'T \log N_i + R'T \log \gamma_i$$

where μ_i° is the chemical potential of the salt component i in the pure liquid state, μ_i is that of the component i in a mixture with the molar fraction N_i, and $R' = \log_{10} R$.

Consider the anion equilibrium :

$$Cl^- + \tfrac{1}{2}Br_{2(g)} = Br^- + \tfrac{1}{2}Cl_{2(g)} \ldots\ldots\ldots\ldots\ldots\ldots (1a)$$

in a salt melt containing the cations Na^+ and K^+. There are five binary mixtures. The symbols used for these, and the corresponding subscripts used for N, a, and γ of the components, are shown in Table I.

System 5 corresponds to a mixture of chloride and bromide, each component having mixed cations in the same ratio n_{Na^+}/n_{K^+}. With these symbols the equilibrium constant of the mixed system (Na, K)(Cl, Br) will be written :

$$K = \frac{a_{(Na,K)Br} \cdot p^{\frac{1}{2}}_{Cl_2}}{a_{(Na,K)Cl} \cdot p^{\frac{1}{2}}_{Br_2}} = \frac{N_{(Na,K)Br} \cdot p^{\frac{1}{2}}_{Cl_2}}{N_{(Na,K)Cl} \cdot p^{\frac{1}{2}}_{Br_2}} \cdot \frac{\gamma_{(Na,K)Br}}{\gamma_{(Na,K)Cl}}$$

$$= K' \frac{\gamma_{(Na,K)Br}}{\gamma_{(Na,K)Cl}}.$$

(The gas mixture is assumed to be ideal). Similarly, the corresponding equilibrium constants of the two simple systems Na(Cl, Br) and K(Cl, Br) will be :

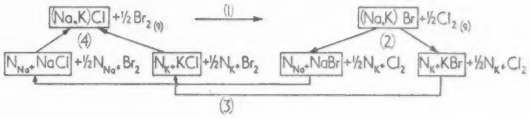
$$K_{Na} = \frac{a_{(Na)Br} \cdot p^{\frac{1}{2}}_{Cl_2}}{a_{(Na)Cl} \cdot p^{\frac{1}{2}}_{Br_2}} = \frac{N_{(Na)Br} \cdot p^{\frac{1}{2}}_{Cl_2}}{N_{(Na)Cl} \cdot p^{\frac{1}{2}}_{Br_2}} \cdot \frac{\gamma_{(Na)Br}}{\gamma_{(Na)Cl}}$$

$$= K'_{Na} \cdot \frac{\gamma_{(Na)Br}}{\gamma_{(Na)Cl}},$$

$$K_K = \frac{a_{(K)Br} \cdot p^{\frac{1}{2}}_{Cl_2}}{a_{(K)Cl} \cdot p^{\frac{1}{2}}_{Br_2}} = \frac{N_{(K)Br} \cdot p^{\frac{1}{2}}_{Cl_2}}{N_{(K)Cl} \cdot p^{\frac{1}{2}}_{Br_2}} \cdot \frac{\gamma_{(K)Br}}{\gamma_{(K)Cl}}$$

$$= K'_K \cdot \frac{\gamma_{(K)Br}}{\gamma_{(K)Cl}}.$$

A thermodynamic relationship between K', K'_{Na}, and K'_K can be derived from the following cycle :



Reaction (1)— 1 mole of (Na, K)Cl is transformed reversibly into (Na, K)Br :

$$\Delta\mu_1 = \mu_{(Na,K)Br} - \mu_{(Na,K)Cl} = -R'T \log K = -R'T \left[\log K' + \log \frac{\gamma_{(Na,K)Br}}{\gamma_{(Na,K)Cl}}\right]$$

Reaction (2)— 1 mole of (Na,K)Br is separated into N_{Na^+} moles of NaBr and N_{K^+} moles of KBr :

$$\Delta\mu_2 = N_{Na^+}\mu^\circ_{NaBr} + N_{K^+}\mu^\circ_{KBr} - \mu_{(Na,K)Br} = -R'T[N_{Na^+} \log a_{Na(Br)} + N_{K^+} \log a_{K(Br)}] = -R'T[N_{Na^+} \log N_{Na^+} + N_{K^+} \log N_{K^+} + N_{Na^+} \log \gamma_{Na(Br)} + N_{K^+} \log \gamma_{K(Br)}]$$

Reaction (3)— N_{Na^+} moles of NaBr are transformed reversibly into NaCl, and N_{K^+} moles of KBr into KCl :

$$\Delta\mu_3 = N_{Na^+}(\mu^\circ_{NaCl} - \mu^\circ_{NaBr}) + N_{K^+}(\mu^\circ_{KCl} - \mu^\circ_{KBr}) = N_{Na^+} R'T \log K_{Na} + N_{K^+} R'T \log K_K = R'T \left[N_{Na^+} \log K'_{Na} + N_{K^+} \log K'_K + N_{Na^+} \log \frac{\gamma_{(Na)Br}}{\gamma_{(Na)Cl}} + N_{K^+} \log \frac{\gamma_{(K)Br}}{\gamma_{(K)Cl}}\right]$$

Reaction (4)— N_{Na^+} moles of NaCl and N_{K^+} moles of KCl are mixed to form 1 mole of (Na, K)Cl :

$$\Delta\mu_4 = \mu_{(Na,K)Cl} - (N_{Na^+}\mu^\circ_{NaCl} + N_{K^+}\mu^\circ_{KCl}) = R'T[N_{Na^+} \log N_{Na^+} + N_{K^+} \log N_{K^+} + N_{Na^+} \log \gamma_{Na(Cl)} + N_{K^+} \log \gamma_{K(Cl)}]$$

From the total cycle the sum of the changes in chemical potential is zero ; hence

$$\log K' = (N_{Na^+} \log K'_{Na^+} + N_{K^+} \log K'_{K^+}) + \left((N_{Na^+} \log \frac{\gamma_{(Na)Br}}{\gamma_{(Na)Cl}} + N_{K^+} \log \frac{\gamma_{(K)Br}}{\gamma_{(K)Cl}} - \log \frac{\gamma_{(Na,K)Br}}{\gamma_{(Na,K)Cl}}\right) + (N_{Na^+} \log \gamma_{Na(Cl)} + N_{K^+} \log \gamma_{K(Cl)}) - (N_{Na^+} \log \gamma_{Na(Br)} + N_{K^+} \log \gamma_{K(Br)}) \quad \ldots(2)$$

From this equation it may be seen that if all the five binary mixtures behaved ideally, log K' would be a linear function with one independent variable

($N_{Na^+} + N_{K^+} = 1$)—the cation composition of the melt :

$$\log K' = N_{Na^+} \log K'_{Na} + N_{K^+} \log K'_{K}$$

The additional terms in the expression for log K' contain activity coefficients corresponding to five binary mixtures. All these coefficients can, at least in principle, be determined independently. It is important, however, that the activity terms will, in general, tend to cancel each other. This will be true if the second term of the deviations from ideality in the three mixtures Na(Cl, Br), K(Cl, Br), and (Na, K)(Cl, Br) are of the same sign. The term is insignificant if the deviations of the (Na, K)(Cl, Br) system are equal to the average of the deviations of the two systems Na(Cl, Br) and K(Cl, Br). Similarly, the third and fourth terms will affect log K' in opposite directions, if the deviations from ideal solutions in the two systems (Na, K)Cl and (Na, K)Br are of the same sign. The linear relationship between log K' and N can therefore be expected to be a good approximation, even in the systems where the single mixtures show considerable deviations from ideality.

A corresponding equation can be developed for an ionic exchange equilibrium in a mixture of non-participating ions of unequal number of charges. The only change is that the mole fraction N is replaced by :

$$N' = \frac{n_{(+)}}{n_{(+)} + 2n_{(++)} + 3n_{(+++)} + \dots}$$

This can be demonstrated on the manganese–iron–exchange equilibrium between liquid iron and slag mixtures of silicates, oxides, phosphates, etc., which is expressed by the reaction :

$$Fe^{++} + \underline{Mn} = \underline{Fe} + Mn^{++}$$

The equilibrium is established in a slag melt containing a mixture of the cations Fe^{++}, Mn^{++}, Ca^{++}, Mg^{++}, and eventually Fe^{3+}, and a mixture of the anions F^-, O^{--}, PO_4^{3-}, SiO_4^{4-}, and eventually FeO_4^{5-}, with the ionic fractions N_{F^-}, $N_{O^{--}}$, $N_{PO_4^{3-}}$, $N_{SiO_4^{4-}}$, and $N_{FeO_4^{5-}}$. The ratios between the anion fractions are independent variables, whilst the fraction $N_{Fe^{++}} : N_{Mn^{++}}$ must correspond to the equilibrium shown.

If the exchange of *one* manganese ion with one ferrous ion in a melt containing only one of the above anions is considered, the following five equilibria and equilibrium constants will be obtained :

K_F for $FeF_2 + \underline{Mn} = \underline{Fe} + MnF_2$
K_O for $FeO + \underline{Mn} = \underline{Fe} + MnO$
K_{PO_4} for $Fe(PO_4)_{\frac{2}{3}} + \underline{Mn} = \underline{Fe} + Mn(PO_4)_{\frac{2}{3}}$
K_{SiO_4} for $Fe(SiO_4)_{\frac{1}{2}} + \underline{Mn} = \underline{Fe} + Mn(SiO_4)_{\frac{1}{2}}$
K_{FeO_4} for $Fe(FeO)_{\frac{2}{5}} + \underline{Mn} = \underline{Fe} + Mn(FeO)_{\frac{2}{5}}$

If (A) = the mixture of $[F_2^{--}, O^{--}, (PO_4)_{\frac{2}{3}}^{--}, (SiO_4)_{\frac{1}{2}}^{--}$, and $(FeO_4)_{\frac{2}{5}}^{--}]$, then the manganese distribution can be written :

$$Fe(A) + \underline{Mn} = \underline{Fe} + Mn(A)$$

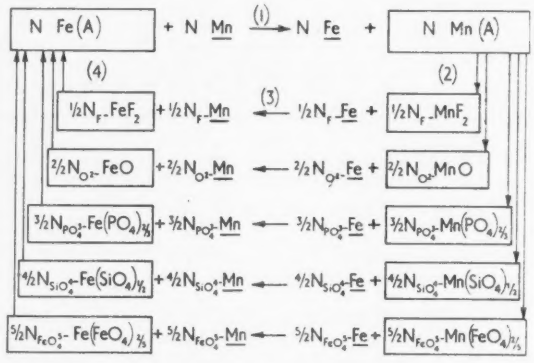
Here, the equilibrium constant $K = \frac{a_{Mn(A)} \cdot a_{\underline{Fe}}}{a_{Fe(A)} \cdot a_{\underline{Mn}}}$,

and $K' = \frac{N_{Mn^{++}} \cdot N_{\underline{Fe}}}{N_{Fe^{++}} \cdot N_{\underline{Mn}}} = \frac{(Mn^{++})[Fe]}{(Fe^{++})[Mn]}$.

Using the same procedure as for the anion equilibria, the thermodynamic relation between K' and K'_F, K'_O, etc., can now be developed. Putting :

$$N = \tfrac{1}{2}N_{F^-} + \tfrac{2}{3}N_{O^{--}} + \tfrac{2}{3}N_{PO_4^{3-}} + \tfrac{4}{5}N_{SiO_4^{4-}} + \tfrac{5}{5}N_{FeO_4^{5-}}$$

gives :



Reaction (1)— N moles of Fe(A) are transformed reversibly into :

$$Mn(A) : \Delta G_1 = -NR'\log K = -NR'\log K' + f_1(\Upsilon)$$

Reaction (2)—N moles of Mn(A) are separated into $\frac{1}{2}N_{F^-}$ moles of MnF_2, $\frac{2}{3}N_{O^{--}}$ moles of MnO, etc. :

$$\Delta G_2 = -R'T(\tfrac{1}{2}N_{F^-}\log\tfrac{1}{2}N_{F^-} + \tfrac{2}{3}N_{O^{--}}\log\tfrac{2}{3}N_{O^{--}} + \dots) + f_2(\Upsilon)$$

Reaction (3)— $\frac{1}{2}N_{F^-}$ moles of MnF_2 are transformed reversibly into FeF_2, $\frac{2}{3}N_{O^{--}}$ moles of MnO into FeO, etc. :

$$\Delta G_3 = \tfrac{1}{2}N_{F^-}R'T\log K_F + \tfrac{2}{3}N_{O^{--}}R'T\log K_O + \dots = R'T[\tfrac{1}{2}N_{F^-}\log K'_F + \tfrac{2}{3}N_{O^{--}}\log K'_O + \tfrac{2}{3}N_{PO_4^{3-}}\log K'_{PO_4} + \dots] + f_3(\Upsilon)$$

Reaction (4)— $\frac{1}{2}N_{F^-}$ moles of FeF_2, $\frac{2}{3}N_{O^{--}}$ moles of FeO, $\frac{2}{3}N_{PO_4^{3-}}$ moles of $Fe(PO_4)_{\frac{2}{3}}$ etc. are mixed to form N moles of Fe(A) :

$$\Delta G_4 = R'T(\tfrac{1}{2}N_{F^-}\log\tfrac{1}{2}N_{F^-} + \tfrac{2}{3}N_{O^{--}}\log\tfrac{2}{3}N_{O^{--}} + \dots) + f_4(\Upsilon)$$

For the total cycle the sum $\sum_{i=1}^{4} \Delta G_i$ must be zero ; hence

$$N\log K' = \tfrac{1}{2}N_{F^-}\log K'_F + \tfrac{2}{3}N_{O^{--}}\log K'_O + \tfrac{2}{3}N_{PO_4^{3-}}\log K'_{PO_4} + \dots + \sum_{i=1}^{4} f_i(\Upsilon)$$

The terms of the activity coefficients will cancel out if all the mixtures behave ideally. Thus :

$$N'_{F^-} = \frac{\frac{1}{2}N_{F^-}}{N}, \quad N'_{O^{--}} = \frac{\frac{2}{3}N_{O^{--}}}{N}, \text{ etc.,}$$

and it follows that :

$$\log K' = N'_{F^-}\log K'_F + N'_{O^{--}}\log K'_O + N'_{PO_4^{3-}}\log K'_{PO_4} + N'_{SiO_4^{4-}}\log K'_{SiO_4} + N'_{FeO_4^{5-}}\log K'_{FeO_4}$$

The N'_{ion} is called[5] the 'electrically equivalent fraction' ; *e.g.* :

$$N'_{PO_4^{3-}} = \frac{3N_{PO_4^{3-}}}{N_{F^-} + 2N_{O^{--}} + 3N_{PO_4^{3-}} + 4N_{SiO_4^{4-}} + 5N_{FeO_4^{5-}}}, \text{ etc.}$$

Similarly, in the general case, a system of i cations

of concentration N_A, N_B, N_C, etc., the equilibrium constant for an anion reaction can be derived :

$$\log K' = \sum_1^i N'_{\text{cation}} \log K'_i + f(\gamma) \ldots\ldots\ldots\ldots (2a)$$

where $N'_{\text{cation}} = \dfrac{n_{(+)}}{n_{(+)} + 2n_{(++)} + \ldots}$

The last term, $f(\gamma)$, contains the activity coefficients corresponding to the different binary systems. For the same reason as before, the first term will ordinarily be valid as a first approximation. Similarly, a first approximation for a cation reaction $A^{(+)} + \underline{P} = B^{(+)} + \underline{Q}$ in a system of i anions of concentration N_X, N_Y, N_Z . . . , etc., is :

$$\log K' = \sum_1^i N'_{\text{anion}} \log K'_i \ldots\ldots\ldots\ldots (2b)$$

Another important point is that, so far as equilibria of the type

$$X^{(-)} = Y^{(-)}$$

with ions of the same valency are concerned, the derived equation will be the same, regardless of whether the slag is considered to be composed of $A^{(+)}$, $B^{(+)}$, $X^{(-)}$, and $Y^{(-)}$ ions or of AX, AY, BX, and BY molecules.

However, if an equilibrium of the type

$$nX^{(m-)} = mY^{(n-)}$$

with ions of different valency is considered, then the ion concept leads to equation (2*a*) whilst the molecule concept leads to the equation

$$\log K_{(\text{molecule})} = \log K_{(\text{ionic})} + k \sum_1^i N_i \log N_i \ldots\ldots (3)$$

where k is a factor that depends on both the anions and the cations in the equilibrium reaction. For the equilibria considered in this paper, $n = m$ except for the distribution of phosphorus between slag and metal according to the equation :

$$\underline{2P} + \underline{5O} + 3O^{--} = 2PO_4^{3-}.$$

For the slags of Winkler and Chipman,[5] which will be discussed later, most of the cations present have a valency of 2, and the above equation can be written in molecule terms as :

$$\underline{2P} + \underline{5O} + 3MeO = Me_3(PO_4)_2,$$

where *Me* is the ' mixture ' of Fe, Mn, Ca, and Mg.

The approximate calculated value of the last term in equation (3) is then $-1{\cdot}0$, and this value is fairly constant over the whole range of compositions investigated. It is therefore not possible from these calculations alone to give preference to either of the two concepts. From a structural point of view, however, it seems unreasonable to assume that molecules such as $Ca_3(PO_4)_2$ are present in the fused slag.

From these considerations it will be evident that the equilibrium constants in the pure unmixed systems (K_A', K_B', etc.) deserve more attention. When the values of these constants are known, it is easy to estimate the approximate value of K' in a slag of an arbitrary composition. Only in a very few cases, however, are experimental data of this kind available. In most cases it is possible, by means of tabulated values of ΔH°, ΔS°, etc., to assign a fairly accurate value to ΔG° for the corresponding reaction between solid compounds. But there is at present a lack of knowledge of heats of fusion and heat capacities of the fused salts, which prevents an accurate calculation of ΔG° for the reaction in the fused state.

APPLICATION OF EQUATION TO MEASURED EQUILIBRIA

In the following, the application of equation (2) will be demonstrated for three important slag/liquid-iron equilibria :

(*a*) The distribution of sulphur
(*b*) Manganese
(*c*) Phosphorus between slag and metal.

The treatment of (*a*) and (*c*) requires a knowledge of the oxygen content in the metal phase. In the extensive experimental work published on slag equilibria, at present only the data of Chipman *et al.* appear to fulfil this requirement. The studies of Winkler and Chipman[6] with basic slags will therefore be used to check the theoretical equation.

The experimental material comprises a fairly large range of slag compositions :

Chief Components					Range
$N_{Ca^{++}}$	...	...	...	...	0·001–0·777
$N_{Fe^{++}}$	...	...	...	...	0·038–0·685
$N_{Mn^{++}}$	...	...	...	...	0–0·445
$N_{Mg^{++}}$	...	...	...	...	0·028–0·556
$N_{SiO_4^{4-}}$	...	...	...	...	0·007–0·904
$N_{PO_4^{3-}}$	...	...	...	...	0–0·358
$N_{O^{--}}$	...	...	...	...	0·038–0·950
N_{F^-}	...	...	...	...	0–0·0320

$N_{O^{--}}$ was determined as the difference between the equivalent sums of anions and of cations, apportioning two oxygens to every SiO_2, three to every P_2O_5, and counting those remaining.

The question remains whether Fe^{III} should be considered as a cation (Fe^{3+}) or as an anion (FeO_3^{3-}, eventually FeO_4^{5-}). Probably the latter would be correct in the more basic slags (with a large content of O^{--} and Ca^{++}), and the former in the less basic slags (with a large content of Fe^{++} and SiO_4^{4-}). The difference is not very important, however, except for the slags with a very low value of $N_{O^{--}}$, but here the calculation of the oxygen ion concentration as a difference is also doubtful for other reasons. Basic ions, such as SiO_4^{4-}, will probably contribute to the O^{--} concentration by reactions such as :

$$2SiO_4^{4-} = Si_2O_7^{6-} + O^{--}$$

In the table above, Fe^{III} is estimated as FeO_4^{5-}.

The Equilibria $\underline{O} + S^{--} = \underline{S} + O^{--}$

Atom fractions in the metal phase, indicated in square brackets, may be expressed as :

$$[S] = \frac{n_S}{\Sigma n} \simeq \frac{n_S}{n_{Fe}},$$

where n is the number of atoms in the metal phase. Round brackets indicate the previously defined ionic fractions in the slag (*see* p. 64).

The calculation of $K' = \dfrac{[S]\ (O^{--})}{[O]\ (S^{--})}$

in the temperature interval 1570–1638° C. given in Fig. 1 shows that K' is reasonably constant over the whole experimental range, and that :

$$\log K'_{1600^\circ C.} \simeq 1{\cdot}65.$$

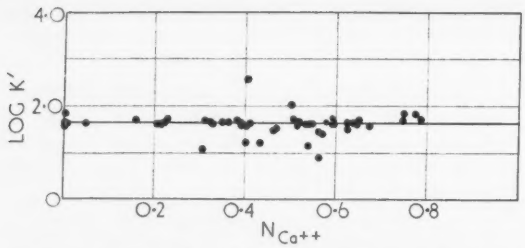


Fig. 1—Dependence of the sulphur–oxygen exchange constant on the ionic fraction of calcium. (Data of Winkler and Chipman ; temperature 1570–1638° C.)

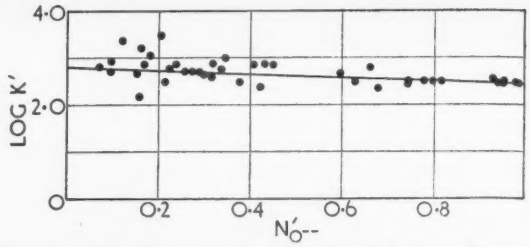


Fig. 2—Dependence of the manganese–iron exchange constant on the electrically equivalent ionic fraction of oxygen. (Data of Winkler and Chipman ; temperature 1570–1638° C.)

From equation (2*a*) the following approximation is obtained :

$$\log K' = N_{Ca^{++}} \log K'_{Ca} + N_{Fe^{++}} \log K'_{Fe} + N_{Mn^{++}} \log K'_{Mn} + N_{Mg^{++}} \log K'_{Mg} \ldots (4)$$

Comparing this equation with the experimental value of log K', two conclusions may be drawn :

(i) The slag behaves ideally, so far as the exchange of S−− and O−− is concerned.

(ii) The values of log K'_{Ca} and log K'_{Fe}, the two dominating terms in equation (4), cannot differ very much.

The subtraction of the two equations :

$$\underline{O} + FeS = \underline{S} + FeO$$

and

$$\underline{O} + CaS = \underline{S} + CaO$$

gives :

$$FeS + CaO = FeO + CaS.$$

The variation of log K' with the slag composition indicates a value of $\Delta G^\circ_{1600^\circ C.} \simeq 0 \pm 2$ kg.cal. for the above reaction. The value of ΔG° for the corresponding reaction with solids is $\Delta G^\circ_{1600^\circ C.} \simeq 7$ kg. cal., which would correspond to a difference :

$$\log K'_{Ca} - \log K'_{Fe} = -0{\cdot}8.$$

From this it is evident that the values of ΔG° for the reaction in the solid state cannot generally be used for an accurate calculation of the values of K'_i (*see* equations 2*a* and 2*b*).

The Equilibrium $\underline{Mn} + Fe^{++} = Mn^{++} + \underline{Fe}$

Over the range 1570–1638° C. the values of the constant :

$$K' = \frac{(Mn^{++})}{(Fe^{++})\,[Mn]}$$

show a small but definite variation with the anion composition of the slag. This is shown in Fig. 2, where log K' is plotted against $N'_{O^{--}}$, the electrically equivalent fraction of oxygen ions. From equation 2*b* :

$$\log K' = N_{O^{--}} \log K'_O + N_{SiO_4^{4-}} \log K'_{SiO_4} + N_{PO_4^{3-}} \log K'_{PO_4} + (N_{S^{--}} \log K'_S + N_{F^-} \log K'_F + N_{FeO_4^{5-}} \log K_{FeO_4})$$

Table II

THEORETICAL VALUES OF MANGANESE DISTRIBUTION COMPARED WITH EXPERIMENTAL DATA DERIVED BY WINKLER AND CHIPMAN[6]

Concentration Ranges

$N_{Ca^{++}}$	0·004–0·675	$N_{SiO_4^{4-}}$	0·028–0·904
$N_{Fe^{++}}$	0·075–0·609	$N_{PO_4^{3-}}$	0–0·307
$N_{Mn^{++}}$	0·013–0·445	$N_{O^{--}}$	0·038–0·920
$N_{Mg^{++}}$	0·034–0·443	N_{F^-}	0·339

Heat	Slag Test	Manganese Distribution, log K'			Remarks
		Observed	Calculated		
			With Fe^{3+}	With FeO_4^{5-}	
E—40	17	2·3	2·3	2·3	With CaF_2
E—32	20	2·4	2·4	2·5	Without P
E—39	22	2·5	2·5	2·6	
E—37	12	2·5	2·9	3·0	Small amounts Mn^+
E—38	16	2·5	2·5	2·5	
E—39	8	2·7	2·7	2·8	
E—39	14	2·7	2·8	2·8	
E—32	22	2·8	2·7	2·7	Without P
E—34	27	2·8	3·0	3·1	Small amounts Fe^{++} ; Larger amounts Mg^{++}
E—32	27	2·9	2·8	2·9	Without P
E—36	22	2·9	2·8	2·9	
E—34	12	2·9	2·9	3·0	
E—36	8	2·9	2·9	3·0	
E—32	24	2·9	2·8	2·9	Without P
E—37	14	3·4	3·0	3·1	
E—37	4	3·5	3·0	3·2	Metal analysis not reliable

where K'_O corresponds to the equilibrium in a slag of pure oxides, K'_{SiO_4} of pure orthosilicates, K'_{PO_4} of pure orthophosphates, etc. The equilibrium :

$$\underline{Mn} + FeO = MnO + \underline{Fe}$$

has been investigated by Körber and Oelsen,[7] who give the following equation for log K'_O :

$$\log K'_O = \frac{6234}{T} - 1{\cdot}0263.$$

At 1600° C., log $K'_O = 2{\cdot}3$. The same equilibrium has also been investigated by Chipman, Gero, and Winkler,[8] who found (in the present authors' terminology) that log $K'_O = 2{\cdot}5$ at 1600° C. These two values of K'_O agree fairly well with that of 2·4 evaluated by extrapolating the experiments of Winkler and Chipman[6] to $N'_{O^{--}} = 1$ (*cf.* Fig. 2).

Körber and Oelsen[9] also examined the equilibrium :

$$\underline{Mn} + FeO\ (SiO_2)_x = MnO\ (SiO_2)_x + \underline{Fe}$$

in a slag saturated with SiO_2. They found that :

$$\log K'_{SiO_x} = \frac{7900}{T} - 1{\cdot}172.$$

At 1600° C. this gives log $K'_{SiO_x} = 3{\cdot}05$. It is interesting that this value is not very different from log K'_{SiO_4} evaluated by extrapolation of log K' to $N'_{SiO_4^{4-}} = 1$, which gives $3{\cdot}1 \pm 0{\cdot}3$. However, this value of log K'_{SiO_4} is, however, less reliable than the extrapolated value of log K'_O ; in only five slags was $N'_{SiO_4^{4-}} > 0{\cdot}8$, and its highest value did not exceed 0·93. Thermal data for the estimation of K'_{SiO_4} and of the minor terms log K'_{PO_4}, log K'_F, etc., are still not available in the literature.

The experimental values of log K' are best fitted by the equation :

$$\log K' = 3N'_{FeO_4^{5-}} + 3{\cdot}1\,N'_{SiO_4^{4-}} + 2{\cdot}5\,N'_{PO_4^{3-}} + 2{\cdot}4\,N'_{O^{--}} + 1{\cdot}5\,N'_{F^-}$$

As the polarization properties of the anions increase in the sequence PO_4^{3-}, SiO_4^{4-}, O^{--}, S^{--}, the values of the constants would be expected to change in the same order, but the experimental sequence seems to be $SiO_4^{4-} > PO_4^{3-} \simeq O^{2-}$.

Since the differences between log K'_O, log K'_{SiO_4}, etc., are obviously small, it is possible that the variation of log K' with the composition of the slag actually arises from the activity terms of equation (2). If so, the chosen values of K'_{SiO_4} and K'_{PO_4} are only empirical constants without real physical significance. The question can be settled only by experimental determination of the constants K'_{SiO_4} and K'_{PO_4}.

Table II shows how the equation fits the experimental data of Winkler and Chipman for the temperature interval 1600 ± 10° C. The calculated values of log K', with only a few exceptions, agree satisfactorily with the observed values.

The Equilibrium $\underline{2P} + \underline{5O} + 3O^{--} = 2PO_4^{3-}$

The value of the constant :

$$K' = \frac{(PO_4^{3-})^2}{[P]^2\,[O]^5\,(O^{--})^3}$$

over the range 1570–1638° C. is greatly influenced by the cation composition of the slag. This is shown in Fig. 3 in which log K' is plotted against $N_{Ca^{++}}$. From equation (2*a*) :

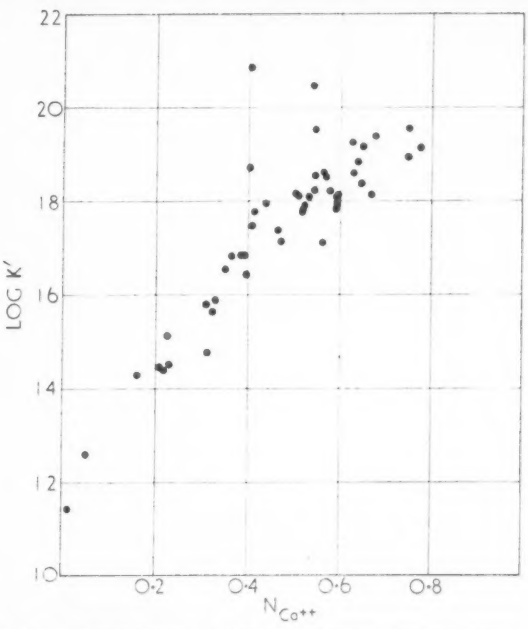


Fig. 3—Dependence of the phosphorus–oxygen equilibrium constant on the ionic fraction of calcium. (Data of Winkler and Chipman ; temperature 1570–1638° C.)

$$\log K' = N_{Ca^{++}} \log K'_{Ca} + N_{Fe^{++}} \log K'_{Fe^{II}} + N_{Mn^{++}} \log K'_{Mn} + N_{Mg^{++}} \log K'_{Mg} + (N_{Fe^{3+}} + \log K'_{Fe^{III}})$$

where K'_{Ca}, $K'_{Fe^{II}}$, K'_{Mg}, etc., correspond to the equilibria :

$$\underline{2P} + \underline{5O} + 3CaO = Ca_3(PO_4)_2$$
$$\underline{2P} + \underline{5O} + 3FeO = Fe_3(PO_4)_2$$
$$\underline{2P} + \underline{5O} + 3MgO = Mg_3(PO_4)_2$$

No experimental data is available for the calculation of K'_{Ca}, $K'_{Fe^{II}}$, etc. Hence, it is only possible at present to estimate these quantities from the slag equilibrium data by extrapolating log K' to $N_{Ca^{++}} = 1$, $N_{Fe^{++}} = 1$, etc. Extrapolation gives :

$$\log K'_{Ca} = 21\ (\pm 1)$$
$$\log K'_{Fe} = 12\ (\pm 3).$$

Log K'_{Mg} and log K'_{Mn} cannot be accurately evaluated, because their ion fractions never exceed 0·45 and 0·56, respectively.

As the polarizing power of the cations increases in the sequence Ca^{++}, Mg^{++}, Mn^{++}, and Fe^{++}, the values of log K'_{Mg} and log K'_{Mn} can be estimated to lie between those for log K'_{Ca} and log K'_{Fe}. This is also in agreement with experimental results. The following values seem to fit the experimental data best :

$$\log K'_{Mg} = 18$$
$$\log K'_{Mn} = 13.$$

If $K'^{(1)}$ and $K'^{(2)}$ are the equilibrium constants when Fe^{III} is assumed to be present as Fe^{3+} and FeO_4^{5-}, respectively, then :

$$\log K'^{(2)} = 21N_{Ca^{++}} + 12N_{Fe^{++}} + 18N_{Mg^{++}} + 13N_{Mn^{++}}$$

In Table III, the observed values of log $K'^{(1)}$ and log $K'^{(2)}$ are compared with the experimental values

Table III

THEORETICAL VALUES OF PHOSPHORUS DISTRIBUTION COMPARED WITH EXPERIMENTAL DATA DERIVED BY WINKLER AND CHIPMAN[6]

The concentration ranges are not very different from those of Table II

Heat	Slag Test	Distribution of Phosphorus		
		log $K'^{(1)}$	log $K'^{(2)}$	
		Observed	Observed	Calculated
E—38	16	14·1	14·3	15·0
E—36	22	15·2	15·8	16·1
E—29	13	15·9	16·4	16·0
E—29	10	16·0	16·5	15·8
E—36	8	16·1	16·8	17·9
E—37	22	16·4	17·2	17·4
E—30	16	16·5	17·4	17·6
E—30	4	16·6	17·4	17·3
E—37	4	17·4	17·8	18·1
E—42	3	17·2	17·9	18·6
E—30	18	16·7	17·9	17·7
E—42	6	17·6	18·1	18·6
E—39	14	17·7	18·1	17·9
E—39	22	17·8	18·2	17·5
E—37	12	17·7	18·5	18·3
E—39	8	18·2	18·6	18·3
E—37	14	18·2	18·6	18·5
E—42	12	18·1	18·9	19·0
E—40*	17	18·9	19·3	18·7
E—34	12	18·6	19·5	18·3
E—34	27	18·8	20·5	18·9

* CaF_2 added

calculated from this equation, for the temperature interval $1600 \pm 10°$ C. There is fairly good agreement.

So long as the values of K'_{Ca}, $K'_{Fe^{II}}$, etc., can only be determined from the experimental slag data by assuming the validity of equation (2), it is uncertain whether the variation of log K' with cation composition is really linear, or whether the activity coefficient terms have an appreciable influence which causes curvature.

An almost linear variation of log K' is, however, indicated by the values of K'_{Ca} and K'_{Fe} which, although not very accurate, can be compared with the values of K'_O and K'_{PO_4} from the equilibrium:

$$\underline{Mn} + Fe^{++} = Mn^{++} + \underline{Fe}.$$

The following figures show that the difference between the values of ΔG° is within the limits of error:

		Approximate value of $\Delta G^\circ_{1600°C}$
I	$\underline{2P} + \underline{5O} + 3FeO = Fe_3(PO_4)_2$	$-12RT$
II	$\underline{2P} + \underline{5O} + 3MnO = Mn_3(PO_4)_2$	$-13RT$
I–II	$3FeO + Mn_3(PO_4)_2 = 3MnO + Fe_3(PO_4)_2$	$(1 \pm 2)RT$
III	$3FeO + \underline{3Mn} = \underline{3Fe} + 3MnO$	$-7{\cdot}2\,RT$
IV	$Fe_3(PO_4)_2 + \underline{3Mn} = \underline{3Fe} + Mn_3(PO_4)_2$	$-7{\cdot}5\,RT$
III–IV	$3FeO + Mn_3(PO_4)_2 = 3MnO + Fe_3(PO_4)_2$	$(0{\cdot}3 \pm 1)RT$

Herasymenko and Speight[10] claim that log K' for the dephosphorization of steel also varies with the N_{F^-} in the slag. This variation disappears, however, when instead of Herasymenko's concentration definition:

$$N_{A^+} = \frac{n_{A^+}}{\Sigma n_{(+)} + \Sigma n_{(-)}}, \text{ etc.,}$$

that of Temkin[2] is used, *i.e.*:

$$N_{A^+} = \frac{n_{A^+}}{\Sigma n_{(+)}}, \text{ etc.}$$

The definition of an ideal fused salt mixture according to Herasymenko seems to resemble statistically an ionic gas mixture, since the distribution of the ions is independent of the sign of their electrical charge. This cannot be true, however, because the same electrostatic forces that are supposed to keep the atoms of the slag in a condensed state must necessarily arrange them in such a way that a positive ion is surrounded by a negative ion, and vice versa.

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Some Further Experiments with Rimming Ingots

By D. Binnie, Ph.D., A.R.T.C., F.I.M.

SYNOPSIS

This analysis of 2-ton ingots of rimming steel cooled in refractory-lined moulds shows that these larger ingots have similar features to those of the smaller 3-cwt. ingots examined previously, except that there was a general rise in impurities towards the axis of the larger ingots. They differ from ingots made in conventional hematite moulds, having no peak value of the impurities at the rim/core junction and no clear indication of minimum values in the rim itself. This shows a need for revision of existing theories on rimming steel.

Introduction

In an earlier paper[1] the author compared the characteristics of 3-cwt. ingots of rimming steel teemed into refractory-lined moulds and into chill moulds, and it was thought desirable to continue the work on heavier ingots.

Mitchell[2] concluded that where extreme purity of the rim is desirable this can be attained better in large than in small ingots, provided that the initial material has sufficiently vigorous effervescence to be controlled by aluminium. The ratio of rim to core increased as the ingot weight was reduced. Also,[3] the ratio of rim to core does not depend on the chemical analysis of the ingot.

Swinden[4] and his collaborators experimented with heats cooled in a magnesite crucible in an 18-lb. high-frequency furnace and obtained rimming steel. Marked differences in sulphur content occurred between the rim and the core.

Hayes and Chipman[5] calculated the analytical curves likely to be obtained on rimming steel on the basis of differential freezing modified by the entrapment of some of the excess impurities of the liquid metal in the growing crystals at the solidifying interface. On this basis, using arbitrary constants, equations could be found which would give graphs approximating to the analytical curves of rimming steel generally, but this method of attack should not be carried too far.

Andrew[6] questioned that the differential freezing of steel was sufficient reason to account for minor and major segregations in steel ingots. He maintained that segregation arose while the steel was in the liquid state and considered the possibility of an immiscible layer high in impurities.

Hultgren and Phragmen[7] discussed the freezing of rimming steel, when chilling caused the skin near the surface to have the same composition as the cast liquid metal. Carbon and oxygen decreased together to a certain depth where, for steels above the balanced composition, the carbon reached a minimum and started to increase again, whilst the oxygen still decreased. (*See also* papers by Swinden.[8, 9]) Rimming-steel freezing under the conditions of no sudden chill, however, (the refractory-lined mould approximates to this condition) does not necessarily show a minimum concentration of carbon contrary to the 'balanced composition' concept.

Halley and Plimpton[10] have summarized graphed analyses of rimming-steel ingots. These graphs show the progressive increase in impurities in the core at higher ingot levels.

Macnair[11] carried out extensive work on varying oxygen contents of a series of 1-ton rimming-steel ingots and noticed that the thickness of the rim was reasonably constant from the level-rimmer to the fully rising ingot. His work shows that, within wide limits, the depth of the rim is independent of the degree of oxidation of the rimming steel.

The writer[1a] showed that, using composite moulds, the greatest depth of rim measured from one side occurred at the junction of the chill and refractory lining, presumably because the greatest chill effect occurred at the junction. There was no difference in depth of chill for the 3-cwt. ingot when made in a copper mould or in a hematite mould.

Present Work

This paper deals with ingots weighing a nominal 2 tons and compares those made in hematite and refractory-lined moulds. A pair of ingots from cast 6139 has been examined in both bloom and billet form, and a single ingot, made subsequently in a lined mould from cast 7886, has been examined in sections. The refractory lining was made with 2-in. firebrick splits.

The internal dimensions of all the ingot moulds used were :

18 in. sq. × 16 in. sq. × 6 ft.

and the ingots were teemed through a $1\frac{1}{8}$-in. nozzle.

EXAMINATION OF CAST 6139

The pit analysis of a killed sample of this cast was : Carbon 0·065%, sulphur 0·033%, phosphorus 0·020%, manganese 0·20%.

Two ingots, teemed consecutively, were examined in bloom and in billet. One had been made in a chill mould and the other in a lined mould. The chill-mould ingot was plated after 17 min.

When stripped three hours later, the chill-mould ingot was dull red whereas the temperature of the refractory mould ingot was still high, being estimated at 1250° C.

Both ingots were rolled and a sample was cut, from the middle of each ingot, at the bloom intermediate stage. Representative billet samples were also cut throughout the ingots.

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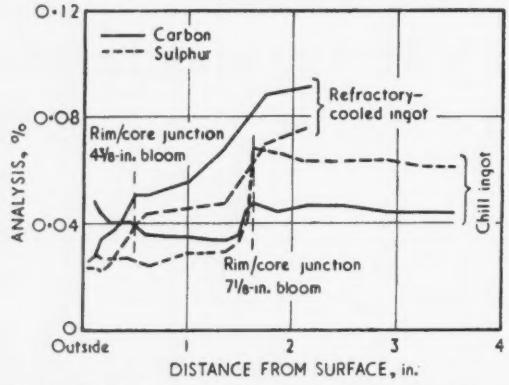


Fig. 1—Carbon and sulphur analyses of 4⅛-in. bloom from the middle of a refractory-cooled ingot, and 7⅛-in. bloom from the middle of a chill ingot

Carbon and sulphur analyses were made on the bloom samples from the middle of the two ingots. Millings were taken by $\frac{1}{16}$-in. steps parallel to the side of the bloom to positions well inside the rim-core junction. Thereafter samples for analysis were obtained from drillings, with a $\frac{3}{8}$-in. drill, to the centre of the section.

From the resultant analyses, shown in Fig. 1, the rim zone of the lined-mould ingot is seen to be purer, the carbon content rising progressively from the surface to the axis of the bloom. The chill-mould ingot shows the usual gradual drop in carbon to a minimum, followed by a steep rise to a peak at the rim-core junction and then remaining fairly steady to the centre. The sulphur analysis follows the same trend as the carbon analysis.

The mean carbon is found to be 0·050% for the refractory-cooled ingot section and 0·042% for the hematite chill-mould section, both being integrated values. The refractory lining has reduced the depth of rim by about one-half (Fig. 2).

The higher carbon in the refractory-cooled ingot caused by the segregation of carbon into the core is shown by the following mean carbon values of the rolled billets :

Ingot Position of Sample after Top and Bottom Crop	Carbon, % Refractory Cooled Ingot	Hematite Chill Ingot
Top	0·040	0·041
$\frac{7}{8}$ height	0·058	0·047
$\frac{3}{4}$,,	0·060	0·042
$\frac{5}{8}$,,	0·056	0·040
$\frac{1}{2}$,,	0·045	0·040
$\frac{3}{8}$,,	0·042	0·040
$\frac{1}{4}$,,	0·040	0·040
$\frac{1}{8}$,,	0·040	0·040

EXAMINATION OF CAST 7886

The pit analysis of the killed sample was : Carbon 0·095%, sulphur 0·034%, phosphorus 0·020%, manganese 0·39%.

A 2-ton ingot of rimming steel made in a lined mould that had a fireclay cover with a vent hole placed on the top, above the steel level, to delay freezing and thus permit the maximum movement of impurities in the slowly freezing ingot, was examined in detail. No partner chill rimming ingot was examined as it was assumed that the rimming characteristics of such an ingot could be accepted from previous work.

Figure 3 is a reproduction of the axial sulphur print of the ingot. Figure 4 shows a photograph of sulphur prints of half cross-sections at various depths of the ingot. They show that the ingot has the essential features of a rimming steel. The rim depth is 2 in. at the upper portion of the ingot and 2½ in. at the lower end. Rim-holes are present two-thirds of the way up the ingot ; there is the usual solid gap between the inner end of the rim-holes and the rim-core boundary, which narrows on passing up the ingot length. A rim cap is also present ; the ingot was not plated and the metal had broken through locally. The blow-hole cavities in the core, close to the top end of the ingot are more pronounced than usual, but otherwise they are quite normal.

The cavity in the core just above middle height is assumed to have been caused by ingot pull ; the ingot had not been easily withdrawn from the mould because liquid metal had entered the interstices in the firebrick joints. A monolithic lining would have been better than jointed brickwork.

The top third of the ingot, penetrating a little into the middle third, gave a darker sulphur print than is usual. This dark area, covering the top third of the ingot, is much more widespread than in conventional rimming ingots, where the dark area is usually confined to the immediate neighbourhood of the contraction cavity. This suggests that there has been a much greater segregation of impurities to the top of the ingot than is found with conventional ingots.

The ingot has a thin skin, *i.e.*, the distance between the skin and the beginning of the rim-holes was small.

Chemical Analysis

Four transverse ingot positions were selected for analysis :

(i) Ten inches from the top of the ingot
(ii) One-third of the way down the ingot length, adjacent to the cut on the sulphur print shown in Fig. 3
(iii) Two-thirds of the way down the ingot length, adjacent to the cut on the sulphur print shown in Fig. 3
(iv) Four inches from the bottom of the ingot.

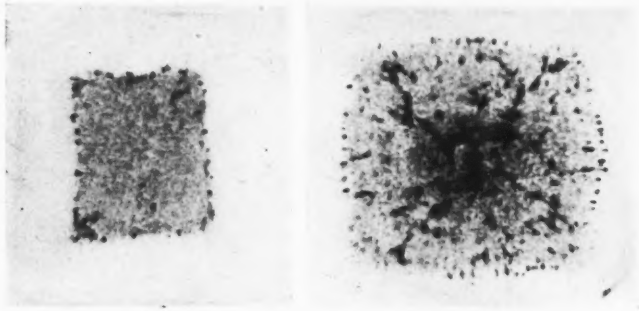
In position (i) 11 holes were drilled with a $\frac{5}{8}$-in. drill, from the surface to the centre. In the other positions millings were taken by $\frac{1}{16}$-in. steps from the surface to a depth of 4 in., well inside the core. Thereafter, millings were taken, with a $\frac{1}{4}$-in. cutter, every $\frac{1}{2}$ in. until close to the axis. The last milling cut was in the area of the axis.

Analysis was concentrated on carbon and sulphur ; phosphorus and manganese being analysed in less detail.

The results obtained are shown in Fig. 5. They exhibit the following trends :

Position (i)—The trend of analysis from this survey is that the carbon, sulphur, phosphorus, and manganese contents rise almost steadily from the surface to the centre of the ingot. The curves representing the elements are similar in type to those obtained from positions (ii) and (iii) but attain higher maxima.

Position (ii)—The carbon content rises from 0·034% at the skin to a level of 0·040%, remaining at this



(a) (b)

Fig. 2—Sulphur prints of billets from cast 6139 : (*a*) From chill ingot ; (*b*) from refractory-cooled ingot

Fig. 3—Sulphur print of refractory-cooled 2-ton ingot from cast 7886

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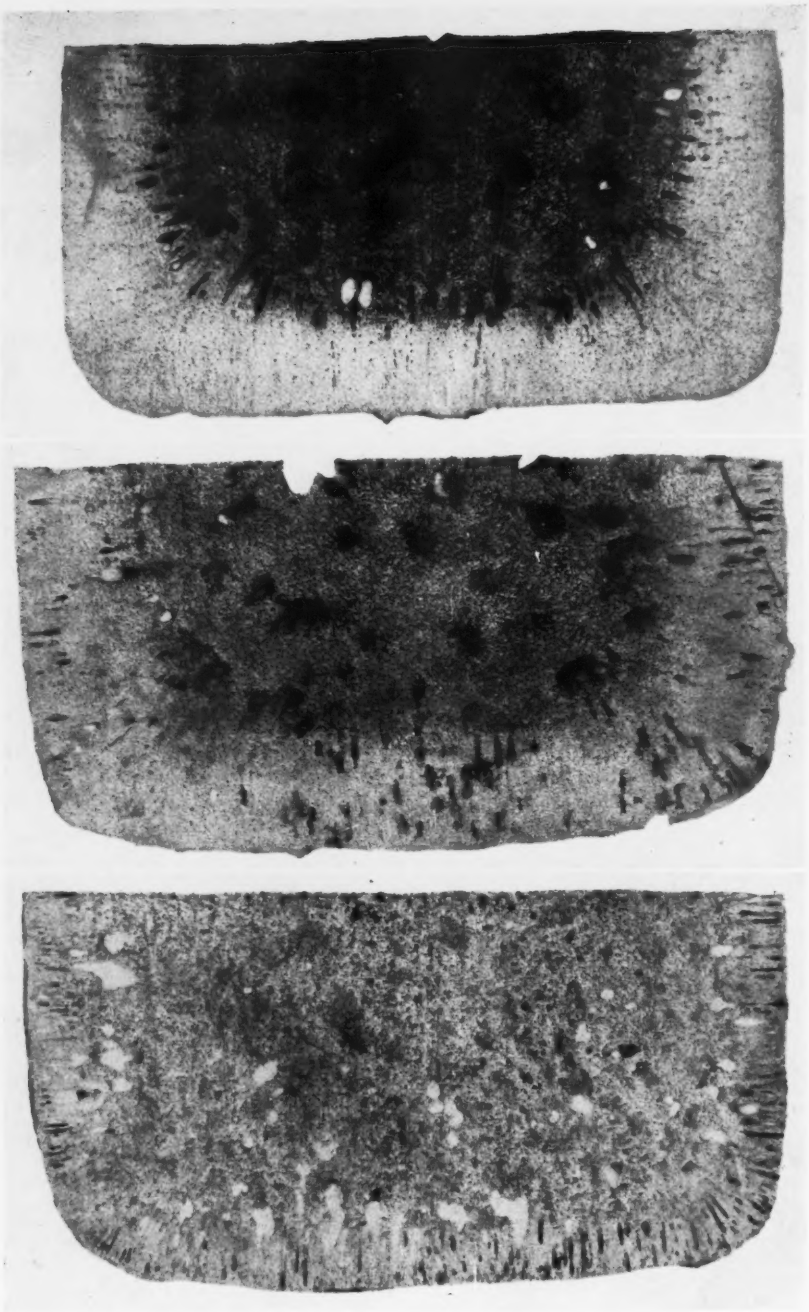

Fig. 4—Sulphur prints of half-cross-sections from cast 7886 : (*a*) One-third down ingot ; (*b*) two-thirds down ingot ; (*c*) four inches from bottom of ingot

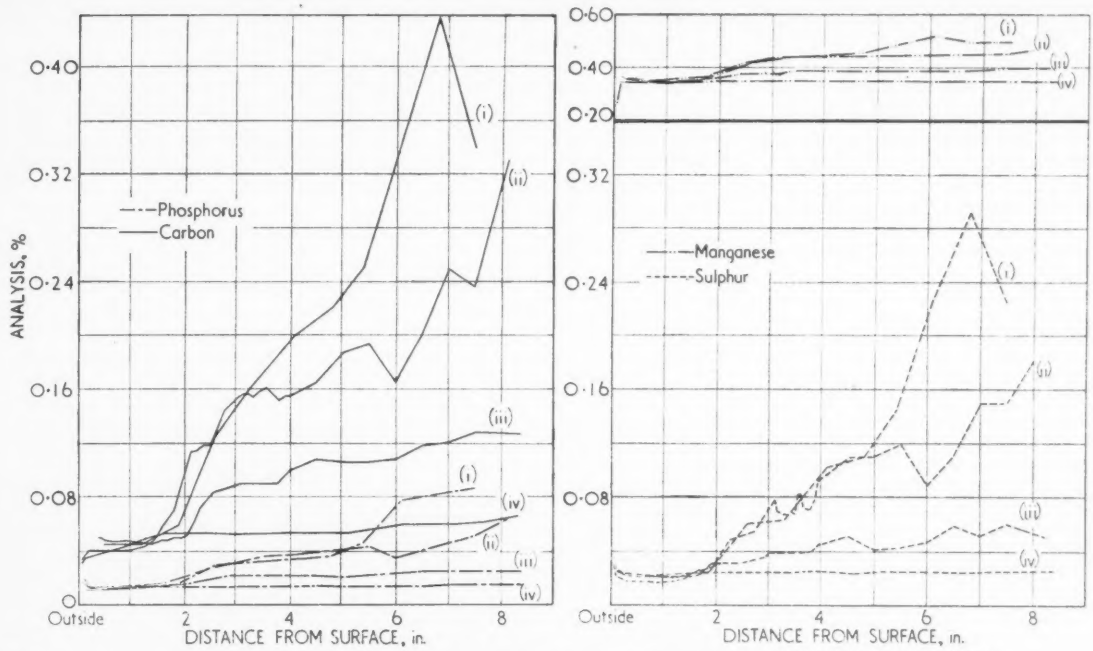

Fig. 5—Analyses of carbon, phosphorus, manganese, and sulphur contents of ingot from cast 7886 at different levels:

(i) Ten inches from top of ingot
(ii) One-third down ingot
(iii) Two-thirds down ingot
(iv) Four inches from bottom of ingot

level for 1 in. and then rising progressively until it reaches 0·33% at the ingot centre.

Sulphur follows the same trend as carbon and from a depth of $\frac{3}{8}$ in. rises progressively from about 0·017% to 0·18% at the ingot centre.

Phosphorus and manganese follow the trend of carbon and sulphur but to a lesser extent.

Position (iii)—The carbon content at a depth of $\frac{3}{8}$ in. is about 0·047%, and it remains steady within the rim to a depth corresponding to the rim/core junction, then it rises progressively and reaches 0·128% near the centre of the ingot.

In the rim both the carbon and sulphur contents in this part of the ingot are higher than further up, *i.e.*, in position (ii). This is in keeping with the properties of conventional rimming steel, which shows a purer rim higher up in the ingot.

Sulphur again follows the same trend as carbon, phosphorus, and manganese, but to a lesser extent.

Position (iv)—The carbon content rises steadily from the skin towards the rim/core junction, beyond which point it is steady until nearer the ingot centre, where it rises slightly.

In this part of the ingot the sulphur, phosphorus, and manganese analyses give steady values, with only minor variations, from the skin to the centre.

The 3-cwt. ingots[1b] previously examined did not show the steep segregation in the core of the ingot from the refractory-lined mould. In this respect the 3-cwt. ingots differ from those weighing 2 tons.

Gas Determinations*

Oxygen, hydrogen, and nitrogen contents were determined on ingot slices cut transversely from the half-ingot, the top slice one-third of the depth from

* These determinations were kindly carried out and reported here by Mr. G. E. Speight, The United Steel Companies, Ltd., Stocksbridge.

Table I

GAS ANALYSIS OF REFRACTORY-COOLED INGOT OF CAST 7886

Ingot-slice Position	Distance from Edge of Slice to Centre of Specimen, in.	Position Represented	Oxygen, %	Hydrogen, ml./100 g.	Nitrogen, %
Top	$\frac{3}{16}$	Edge of rim	0·016	1·5	0·002
	$\frac{13}{16}$	Mid-rim	0·005$_5$	1·0	0·002
	$1\frac{5}{8}$	Rim/core junction	0·004	0·9	0·003
	$2\frac{3}{4}$	Just inside core zone	0·017	0·9	0·005
	5	Midway between core junction and centre of ingot	0·017$_5$	1·8	0·005
Bottom	$\frac{3}{16}$	Edge of rim	0·019$_5$	1·3	0·003
	$\frac{13}{16}$	Mid-rim	0·009	0·8	0·002
	$1\frac{5}{8}$	Rim/core junction	0·0065	0·6	0·002$_5$
	$2\frac{3}{4}$	Just inside core zone	0·010	1·5	0·004$_5$
	5	Midway between core junction and centre of ingot	0·011$_5$	1·1	0·004$_5$

the top of the ingot, and the bottom slice two-thirds of the depth, adjacent to the corresponding cuts for chemical analyses. Specimens, 22 mm. long × 10 mm. dia., were prepared from the two slices at intervals between the outside and the centre of the ingot, and vacuum-fusion determinations were carried out by the normal method at 1600–1650° C. Table I gives results of the vacuum-fusion determinations together with the positions of the specimens examined.

Examination of the oxygen contents of the top section shows the usual marked fall across the rim zone with a marked rise in the core zone to a value slightly higher than the highest value recorded at the extreme edge of the ingot. The bottom section shows a similar fall in oxygen content across the rim, the values being slightly higher than in the former case. This section, however, does not show the marked increase in the core zone, the oxygen content of the mid-core position being considerably lower than the corresponding position for the top section. Consequently the average oxygen content of the bottom section is somewhat lower than that of the top section. The hydrogen contents appear to be lower than are usually obtained with rimming steel and, whilst the variations are not large, they appear to follow a similar trend to the oxygen contents.

Nitrogen contents show a gradual increase from edge to centre in both cases.

CONCLUSIONS

Analysis of refractory-cooled ingots did not show a fall in carbon, sulphur, phosphorus, manganese, or nitrogen content across the rim. The oxygen content did fall in the rim but followed the rising trend of the other elements in the core. Thus, normal rimming steel, when frozen at a very slow rate of heat-extraction, showed a greatly reduced rimming action, the contents of these elements depending upon the initial solidus composition at the surface and rising to a peak value at the axis, *i.e.*, at the last position to freeze.

This indicates that the characteristics of the conventionally cooled ingot—an initial fall followed by a rise to a peak value at the rim/core junction and a subsequent steady value across the core—are superimposed on the freezing steel by the rapid heat-extraction, *i.e.*, by chilling.

Acknowledgments

The author thanks the Lancashire Steel Corporation, Ltd., for granting facilities for the work and for permission to publish the results; Mr. W. A. Jenks for supervising the experimental tests; Mr. J. M. Harrison for the chemical analysis; and Mr. J. C. Booth for the photographs.

Mr. Speight's contribution on gas determinations has been most helpful and is gratefully acknowledged.

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Correspondence on the Paper—

THE CARBIDE PHASE IN IRON–CARBON–SILICON ALLOYS

*By W. S. Owen**

(The following reply by Dr. Owen to a written contribution to the discussion from Dr. N. J. Petch (J. Iron Steel Inst., 1952, vol. 170, March, p. 241) was received too late for inclusion with the Authors' Reply to the discussion.)

Dr. Owen wrote in reply: We referred to the lines used by Dr. Petch† because it seemed to be the most convenient method of example. The θ values given in the paper referred to the radiation that was used in the experiments under discussion, and it was not intended to imply that these were the θ values used by Dr. Petch.

It was decided to use the lattice parameters reported by Hume-Rothery, Raynor, and Little,‡ because at the time these appeared to be the most accurate available. The data obtained during the course of the work on iron–carbon–silicon alloys agreed with these parameters. However, this is not a very good test of their accuracy, because in both cases the same experimental method was used. More recently it has come to my attention that, in the case of cementite extracted from high-purity plain-carbon steels, there may be a very small, but significant, error in the parameters given by Hume-Rothery *et al.* This suggested error is in the direction predicted by Dr. Petch's work. It appears that further careful work, using a variety of highly monochromatized radiations, is necessary.

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* *J. Iron Steel Inst.*, 1951, vol. 167, pp. 117–120.

† N. J. Petch, *J. Iron Steel Inst.*, 1944, No. I, pp. 143p–150p.

‡ W. Hume-Rothery, G. V. Raynor, and A. T. Little, *Ibid.*, 1942, No. I, pp. 143p–149p.

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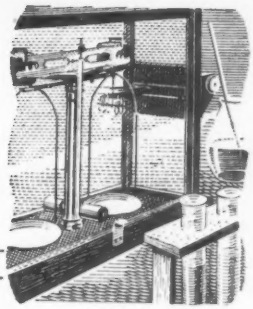

Determination of Molybdenum in Iron and Low-Alloy Steels Containing up to 0·5% of Tungsten

By the Methods of Analysis Committee

SYNOPSIS

A method for the determination of 0·02–2·0% of molybdenum in low-alloy steels containing up to 0·5% of tungsten is described. The method is based on a preliminary separation of the molybdenum from iron and from most of the other common alloying elements as the α-benzoinoxime complex. The behaviour of tungsten in this reaction has been studied and a method for overcoming the interference of that element, depending on the precipitation of molybdenum trisulphide in the presence of tartrate ions, is suggested. Complete precipitation of molybdenum trisulphide can best be achieved by decomposition of an alkali thiomolybdate with dilute mineral acid.

Introduction

THE work has been carried out by the Pig Iron, Carbon, and Low Alloy Steels Analysis Sub-Committee, constituted as follows:

Mr. S. W. CRAVEN (*Chairman*)	I.C.I. Ltd., Alkali Division
Mr. O. BEADLE	Cargo Fleet Iron Co., Ltd.
Mr. W. F. CHARTERIS*	Colvilles Ltd.
Mr. L. E. GARDNER	Edgar Allen and Co., Ltd.
Mr. C. L. GRAYSON†	English Steel Corporation, Ltd.
Mr. J. M. HARRISON	Lancashire Steel Corporation, Ltd.
Mr. J. D. HILL*	Bragg Laboratory, N.O.I.D.
Mr. J. MCCROSSON†	Colvilles Ltd.
Mr. A. W. REED	Consett Iron Co., Ltd.
Mr. N. D. RIDSDALE	Bureau of Analysed Samples, Ltd.
Mr. C. W. SHORT	J. Lysaght, Ltd.
Mr. F. SPEED†	Dorman, Long and Co., Ltd.
Mr. H. J. TURNER	Steel Peech and Tozer
Mr. W. WESTWOOD	British Cast Iron Research Association
Mr. J. H. WRIGHT*	Dorman, Long and Co., Ltd.
Mr. J. O. LAY (*Secretary*)	British Iron and Steel Research Association.

The intention of the Sub-Committee in formulating a standard method for the determination of molybdenum was to use the procedure for the analysis of the series of low-alloy steel Spectrographic Standards,[1] which were being prepared on behalf of the British Iron and Steel Research Association. These steels were supposed to contain no tungsten, but subsequent examination revealed in many of the steels amounts of this element sufficient to cause appreciable interference with simple, established methods for the determination of molybdenum.

Consideration of the procedures available for the separation of molybdenum from iron and the elements commonly associated with it in low-alloy steels suggested that the most useful reagent would be α-benzoinoxime.[2–5] It is claimed[6, 7] that from acidic solutions α-benzoinoxime precipitates molybdate and tungstate ions quantitatively, whilst the ions of chromate, vanadate, niobate, tantalate, and divalent palladium may also be wholly or partially precipitated. Under similar conditions silica may also separate Elements which are not precipitated in acid solution include ferrous and ferric iron, aluminium, divalent manganese, nickel, cobalt, arsenic, trivalent chromium, and quadrivalent vanadium. Thus the only element in the majority of low-alloy steels which seemed likely to interfere with the precipitation of molybdenum by α-benzoinoxime was tungsten; the complete separation of these two elements presented some difficulties.

During the initial solution of a steel in acid some of the tungsten separates as tungstic acid but, with amounts of tungsten less than 0·5%, removal by acidic dehydration is seldom complete even if such reagents as cinchonine or rhodamine *B* are also used. The tendency towards incomplete separation increases

* Left 31st March, 1950.
† Joined 31st March, 1950.

Paper MG/D/309/51 of the Methods of Analysis Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association, received 14th January, 1952.

as the percentage of tungsten decreases and, in steels containing small amounts of this element, results for molybdenum were expected to be appreciably high when α-benzoinoxime was used, even after initial dehydration.

A further disadvantage associated with the removal of tungsten as tungstic acid is that the residue after dehydration is liable to adsorb significant amounts of molybdenum, necessitating a further recovery treatment.

For the final separation of molybdenum from associated tungsten it was considered that the most satisfactory procedure would be precipitation of the molybdenum as the trisulphide from a solution containing tartrate. Conflicting statements have been made concerning the quantitative nature of this reaction[8, 9]; the chief disadvantage is that precipitation of the sulphide from acid solution is seldom complete, part of the molybdenum being reduced by hydrogen sulphide to a lower valency state in which it does not form insoluble sulphides. It has been recommended that, following an initial sulphide separation, the filtrate should be reoxidized and given a further treatment with hydrogen sulphide; several retreatments may be necessary in some cases. Precipitation in a pressure bottle has also been suggested; in this way higher concentrations of hydrogen sulphide, and hence more favourable conditions for the complete removal of molybdenum sulphide, are obtained.

It was decided (1) to examine the effect of tungsten during the precipitation of molybdenum by α-benzoinoxime and to find at what tungsten level in relation to the molybdenum content any interference becomes significant, and (2) to determine the best conditions for the complete precipitation of molybdenum sulphide free from tungsten.

Other procedures for the determination of molybdenum were considered, but preliminary trials indicated that the following are unlikely to give acceptable results:

(i) The removal of iron as hydroxide and precipitation of the molybdenum as lead molybdate
(ii) Direct precipitation of molybdenum sulphide from the acid solution of the sample, and reprecipitation of the molybdenum as lead molybdate
(iii) Precipitation with α-benzoinoxime and ignition to molybdic oxide followed by treatment of the weighed residue with ammonium hydroxide and reweighing of the insoluble impurities.

PRELIMINARY INVESTIGATIONS

Initial experiments were carried out on a sample of steel containing approx. 1·5% of molybdenum. Spectrographic examination and colorimetric determinations showed that about 0·04% of tungsten was also present. One set of results was obtained using α-benzoinoxime as precipitant without correction for co-precipitated tungsten. Another series of experiments gave results after purification of the α-benzoinoxime precipitate by sulphide separation in the presence of tartrate or after correction for occluded tungsten, the amount of which was determined colorimetrically in the final residue.

Table I shows that in each case a tungsten separation or correction caused lower results for molybdenum.

A closer examination of the conditions necessary for complete precipitation of molybdenum sulphide free from tungsten was therefore planned so that use could be made of it to study in greater detail the interference of tungsten in the α-benzoinoxime precipitation of molybdenum.

The relative merits of two methods for the final evaluation of the molybdenum content were compared: (*a*) ignition to molybdic oxide at 500–525° C.; (*b*) weighing as lead molybdate. No difficulties were experienced with (*a*) and as it avoids the additional operations necessary in (*b*) it was adopted as standard practice.

PRECIPITATION OF MOLYBDENUM SULPHIDE

The separation of molybdenum as sulphide is usually carried out by saturating a dilute sulphuric solution with hydrogen sulphide. If tungsten is also present tartaric acid is added to prevent co-precipitation. Some molybdenum is usually reduced during the passage of hydrogen sulphide and must be recovered from the filtrate by re-oxidation and further treatment with hydrogen sulphide.

Molybdenum sulphide can also be obtained by saturating the solution of an alkali molybdate with hydrogen sulphide and decomposing the thiomolybdate (*e.g.*, Na_2MoS_4) so formed with dilute hydrochloric or sulphuric acid.

Preliminary experiments were carried out to compare these two procedures. It was assumed that the sulphide separation would be necessary following a preliminary precipitation of the molybdenum as the α-benzoinoxime complex. This step would ensure the removal of almost all the iron and the traces remaining could be removed by treatment of the solution of the oxime complex with sodium hydroxide.

Satisfactory separation of molybdenum from tungsten was obtained with both methods, but that involving prior formation of a thiomolybdate had definite advantages. The sulphide obtained in this way precipitated instantaneously, coagulated readily, and filtered easily and rapidly. Molybdenum sulphide deriving from acid solution, on the other hand, was very fine and apparently non-crystalline; filtration and washing was often slow and difficult. The reoxidation and reprecipitation stage also lengthened the

Table I

EFFECT OF TUNGSTEN ON THE PRECIPITATION OF MOLYBDENUM BY α-BENZOINOXIME

Operator	Molybdenum Found, %		
	No Correction for Tungsten	After Sulphide/Tartrate Separation	After Correction for Tungsten
A	1·48	1·44	...
B	1·46	...	1·44
C	1·51	...	...
D	1·48	1·42	...
E	1·49	...	...
F	1·46	...	...
G	1·50	...	1·46
H	1·51	...	1·48
I	1·47	...	...

Table II

EFFECT OF VARIATION IN ALKALINITY AND ACIDITY AT THE FIRST STAGE OF SULPHIDE PRECIPITATION

Molybdenum Added, g.	Molybdenum Found, g.				
	Alkalinity ≡0·053% NaOH by weight	Alkaline to phenolphthalein	Acid to Methyl Red	Acidity ≡1·6% H_2SO_4 by vol.	Acidity ≡5·0% H_2SO_4 by vol.
0·0010	0·0010	0·0014	0·0014	0·0010	0·0010
0·0050	0·0050	0·0046	0·0050	0·0050	0·0050
0·0100	0·0104	0·0104	0·0100	0·0100	0·0096
0·0250	0·0240	0·0246	0·0240	0·0236	0·0226

Acidity at stage 2 was equivalent to 3·1% of sulphuric acid by volume, except in the last test when it was 5·0%.

process. The principle of thiomolybdate formation was therefore used for investigating the completeness of molybdenum sulphide precipitation under specified conditions. Known amounts of molybdenum were added as ammonium molybdate and 2 g. of sodium tartrate were present in the solution, the volume of which was adjusted to 200 ml. before passing hydrogen sulphide. The procedure was divided into two main stages :

(1) Treatment of the alkaline molybdate solution with hydrogen sulphide to form the thiomolybdate

(2) Decomposition of the thiomolybdate with dilute sulphuric acid and re-saturation with hydrogen sulphide to ensure complete precipitation of molybdenum sulphide.

In one set of experiments changes were made in the alkalinity of the solution before the passage of hydrogen sulphide at stage 1 and in a second series the degree of acidity before the final passage of hydrogen sulphide at stage 2 was varied. In these tests the solutions were brought to the boil and hydrogen sulphide was passed for 10 min. at stage 1 and then for a further 5 min. at stage 2. The precipitated sulphide was filtered, washed with dilute sulphuric acid saturated with hydrogen sulphide, ignited at 525° C., and weighed as molybdic oxide.

The results given in Tables II and III show that complete precipitation of molybdenum sulphide is possible over a wide range of conditions of alkalinity and acidity at the two stages of the method. Alkaline conditions at stage 1, leading to the prior formation of thiomolybdate, were much to be preferred to initial

Table III

EFFECT OF VARIATIONS IN ACIDITY AT THE SECOND STAGE OF SULPHIDE PRECIPITATION

Molybdenum Added, g.	Molybdenum Found, g.					
	Acidity at the second stage of sulphide precipitation, % H_2SO_4 by volume					
	2·8	4·9	6·6	7·9	12·4	19·9
0·0010	0·0010	0·0010	0·0010	0·0010	0·0010	0·0010
0·0050	0·0046	0·0046	0·0040	0·0046	0·0046	0·0046
0·0100	0·0100	0·0100	0·0096	0·0096	0·0096	0·0104
0·0250	0·0246	0·0250	0·0240	0·0240	0·0246	0·0250

Table IV

EFFECT OF TEMPERATURE ON THE PRECIPITATION OF MOLYBDENUM SULPHIDE

Molybdenum Added, g.	Molybdenum Found, g.			
	Hydrogen Sulphide Passed in Hot Solution		Hydrogen Sulphide Passed in Cold Solution	
	A	B	A	B
0·0002	0·0002	...	...	...
0·0010	0·0010	...	0·0011	...
0·0050	0·0051	0·0049	0·0052	0·0051
0·0100	0·0100	0·0101	0·0098	0·0097
0·0500	0·0498	0·0497	0·0494	0·0491
0·1000	0·1000	0·0994	0·1000	0·0996

acidity, particularly as the amount of molybdenum increased. With 0·0250 g. of molybdenum in solution the recovery of molybdenum tended to be incomplete when the solution was acid at stage 1. Increasing the acidity to 19·9% at stage 2, however, did not affect sulphide recovery.

As a check on the reliability of molybdenum precipitation the filtrates, obtained by operating the method under conditions similar to those outlined in Table III (alkalinity at stage 1 ≡ 0·1% NaOH by weight, acidity at stage 2 ≡ 2% H_2SO_4 by volume) on solutions containing from 0·0025 to 0·10 g. of molybdenum, were examined colorimetrically for traces of the element, but no molybdenum was found.

It was noticed that when hydrogen sulphide was used direct from a generator or after passage through a single wash bottle, the final ignited molybdic oxide residues were invariably contaminated with small quantities of ferric oxide. Such contamination was avoided if the gas was passed through three wash bottles in series.

The effect of temperature during the passage of hydrogen sulphide was next studied. In the commonly used reaction between hexavalent molybdenum and hydrogen sulphide in an acid medium, a high concentration of hydrogen sulphide is favourable for the promotion of complete precipitation of the sulphide. As the solubility of the gas in water is greater at low than at high temperatures, a greater concentration of the gas—and hence better conditions for complete precipitation of molybdenum sulphide—would apparently result if the gas were introduced in the cold. Several synthetic solutions having an alkalinity equivalent to 0·1% NaOH by weight at the first stage of precipitation and an acidity of 2% H_2SO_4 by volume at the second stage were made up and tested. The typical results in Table IV and others, covering Mo additions in 10-mg. steps between the results shown, were obtained. In no case was there an error greater than 1 mg. of Mo, and it was apparent that quantitative molybdenum recovery was achieved under both temperature conditions.

The influence of tungsten was examined by making tungstate additions at various molybdenum levels immediately before carrying out precipitation from hot solutions under the conditions described above. No tungsten contamination of the ignited molybdic

Table V

EFFECT OF TUNGSTEN ON THE PRECIPITATION OF MOLYBDENUM SULPHIDE

Molybdenum Added, g.	Tungsten Added, g.	Molybdenum Found, g.
0·0020	0·0020	0·0021
0·0020	0·0100	0·0021
0·0020	0·0500	0·0021
0·0200	0·0020	0·0204
0·0200	0·0100	0·0201
0·0200	0·0500	0·0204
0·0500	0·0020	0·0503
0·0500	0·0250	0·0501
0·1000	0·0020	0·1004
0·1000	0·0250	0·1011

oxide was noticed and satisfactory molybdenum recovery was again obtained (*see* Table V).

LEVEL OF TUNGSTEN INTERFERENCE

Before the method for the determination of molybdenum in low-alloy steels could be further developed it was necessary to define more closely the level at which tungsten interferences should be expected when the complete analytical procedure was applied. A series of synthetic solutions was prepared from pure iron, ammonium molybdate, and ammonium tungstate, and molybdenum determinations were made as follows :

(1) The acidified and oxidized solutions were evaporated to dryness and baked lightly. After treatment with hydrochloric acid any residues were separated by filtration.

(2) Molybdenum was recovered from the residues from (1) by precipitation with hydrogen sulphide in the presence of tartrate and returned to the main filtrate from (1).

(3) Molybdenum was precipitated with α-benzoinoxime, ignited, and weighed as molybdic oxide.

(4) The residues from (3) were dissolved in caustic soda, molybdenum was precipitated as sulphide from tartrate solutions and, after ignition, was reweighed as molybdic oxide.

Comparison of the amounts of molybdic oxide shown at stages (3) and (4), as in Table VI, indicates the extent of tungsten interference.

It is possible to draw the following conclusions from the results in Table VI:

Table VI

INTERFERENCE OF TUNGSTEN IN PRECIPITATION BY α-BENZOINOXIME AND IN THE COMPLETE PROCEDURE

Molybdenum Added, g.	Tungsten Added, g.	Molybdenum Recovered, g.	
		From α-Benzoinoxime Precipitates	After Sulphide Separation
0·0025	Nil	0·0025	0·0027
0·0025	0·0010	0·0027	0·0025
0·0025	0·0020	0·0035	0·0025
0·0025	0·0030	0·0050	0·0025
0·0050	0·0025	0·0060	0·0050
0·0050	0·0050	0·0075	0·0050
0·0050	0·0100	0·0075	0·0050
0·0100	0·0025	0·0110	0·0104
0·0100	0·0050	0·0110	0·0100
0·0100	0·0100	0·0110	0·0100
0·0200	0·0025	0·0214	0·0202
0·0200	0·0250	0·0220	0·0198
0·0500	0·0025	0·0508	0·0500
0·0500	0·0250	0·0518	0·0504

(1) Small amounts of tungsten escaping separation as tungstic acid are co-precipitated with molybdenum during treatment with α-benzoinoxime. No attempt was made to establish whether quantitative precipitation of tungsten is possible under these conditions, but a method for the determination of tungsten using α-benzoinoxime in the presence of added molybdenum has been proposed.[10, 11] Traces of tungsten co-precipitated with molybdenum could be detected visually because of the yellow colour imparted to molybdic oxide by tungstic oxide ; such detection becomes more difficult as the amount of molybdic oxide increases.

(2) Some tungsten is always removed by hydrolysis as tungstic acid but the recommended procedure is successful in recovering any molybdenum carried down with it.

(3) Quantitative recovery of molybdenum is possible using the recommended procedure even with very small amounts of the element associated with similar small amounts of tungsten.

Two small high-frequency furnace ingots were also used to study the behaviour of minor amounts of tungsten associated with molybdenum. Their nominal composition was : 0·01% W, 0·1% Mo in ingot *X*703, 0·2% W, 0·2% Mo in ingot *X*704.

Table VII

EXAMINATION OF TWO INGOTS CONTAINING SMALL AMOUNTS OF MOLYBDENUM AND TUNGSTEN

Ingot Number	Spectrographic Examination		Chemical Determinations of Molybdenum, %	
	Tungsten, %	Molybdenum, %	From wt. of Ignited Oxime Precipitates	After Sulphide Separation
X703	0·005, 0·01, 0·03 (top of ingot) 0·005 (bottom of ingot)	0·10, 0·11, 0·11 0·11	0·13, 0·13 0·14, 0·13	0·11, 0·10, 0·11 0·12, 0·11, 0·11
X704	0·26, 0·31, 0·33, 0·22 (top of ingot) 0·35, 0·11, 0·19, 0·09, 0·17 (bottom of ingot)	0·22, 0·22 0·21, 0·20, 0·22	0·27, 0·28 0·27, 0·25	0·22, 0·23, 0·21, 0·21 0·20, 0·20, 0·19, 0·19

Table VIII

DETERMINATION OF MOLYBDENUM BY FINAL METHOD

Operator	Molybdenum, %			
	Sample 2 (Tungsten 0·03%)	Sample 3 (Tungsten 0·43%)	Sample 4 (Tungsten 0·5%)	Sample 5 (Tungsten Nil)
A	1·48	0·202	...	0·93
B	1·52	0·201	0·026	0·93
C	1·49	0·208	0·028	0·94
D	1·50	0·196	...	0·95
E	1·50	0·193	0·026	0·93
F	1·48	0·205	...	0·96
G	1·49	0·211	0·022	0·98
I	1·50	0·213	0·033	0·96
J	1·48	0·207	0·023	...
Average	1·49	0·204	0·026	0·95

Samples 3 and 4 were also analysed by absorptiometric methods, and results of 0·204 ± 0·007% Mo and 0·024 ± 0·002% Mo were obtained.

Unfortunately, marked irregularities in the distribution of tungsten existed, but comparisons were possible between results for molybdenum by the present chemical method and a spectrographic technique. Contamination by tungstic oxide of the molybdic oxide obtained by direct precipitation with α-benzoinoxime was again demonstrated (*see* Table VII).

RECOMMENDED METHOD

Details of the final recommended method were drawn up as given in the Appendix, and fresh samples were analysed (Table VIII). One of these samples (Sample 5-S.S.3, *see* Table X) was known to have no tungsten present and the sulphide separation procedure was therefore omitted. No tungsten could be detected colorimetrically in the final precipitates from samples 3 and 4.

The final draft standard method was used for the analysis of the Spectrographic Standards, the approximate compositions of which are given in Table IX ; the actual molybdenum figures determined experimentally are given in Table X. No difficulty was experienced in applying the principles involved.

Extensive trials of the method showed that interference from small amounts of tungsten had been overcome. The method has been used for the analysis of a wide range of samples and has been submitted to the British Standards Institution for approval as a standard method.

APPENDIX

Determination of Molybdenum in Low-Alloy Steels Containing up to 0·5% of Tungsten

Solutions Required

Hydrochloric Acid (1 : 19).
Ferrous Sulphate (5% in 5% sulphuric acid).

Table IX

APPROXIMATE COMPOSITION OF SPECTROGRAPHIC STANDARDS

	S.S.1	S.S.2	S.S.3	S.S.4	S.S.5	S.S.6	S.S.7	S.S.8
Silicon, %	0·02	0·25	0·2	0·3	0·6	0·15	0·4	0·8
Manganese, %	0·2	0·02	0·35	0·5	1·1	1·2	1·4	0·8
Nickel, %	5·2	4·1	2·9	2·1	0·55	0·2	0·8	0·05
Chromium, %	0·05	0·2	0·35	0·5	1·0	2·3	1·7	3·1
Molybdenum, %	0·2	0·01	1·0	1·3	1·4	0·5	0·3	0·4
Vanadium, %	0·05	0·45	0·2	0·5	0·25	0·35	0·1	0·65
Copper, %	0·1	0·1	0·5	0·1	0·25	0·2	0·3	0·2

Table X

PERCENTAGE MOLYBDENUM ON SPECTROGRAPHIC STANDARDS

Operator	S.S.1	S.S.2	S.S.3	S.S.4	S.S.5	S.S.6	S.S.7	S.S.8
A	0·185	0·005	0·92	1·27	1·38	0·54	0·325	0·425
B	0·19	0·006	0·90	1·25	1·37	0·535	0·31	0·415
C	0·19	0·010	0·99	1·32	1·42	0·54	0·33	0·44
D	0·175	0·004	0·95	1·27	1·43	0·53	0·34	0·42
E	0·17	0·007	0·95	1·24	1·45	0·54	0·30	0·43
F	0·19	0·008	0·96	1·27	1·42	0·53	0·33	0·43
G	0·185	0·006	0·98	1·31	1·43	0·54	0·315	0·43
H	0·19	0·005	0·95	1·32	1·43	0·55	0·31	0·425
I	0·19	0·010	0·99	1·34	1·40	0·52	0·335	0·42
J	0·17	0·006	0·91	1·36	1·37	0·525	0·325	0·415
K	0·19	0·010	0·94	1·26	1·40	0·54	0·305	0·44
L	0·19	0·007	0·93	1·29	1·39	0·52	0·31	0·42
Average	0·185	0·007	0·95	1·29	1·41	0·535	0·32	0·425
Tungsten, % (approx.)	0·01	0·01	Nil	0·02	0·04	0·05	Nil	0·06

α-benzoinoxime (2% in acetone).
Bromine Water.
Sulphuric Acid (1 : 1).
Sulphuric Acid (1 : 9).
Sulphuric Acid (1 : 99).
Sodium Hydroxide (25%).
Sulphuric Acid–α-benzoinoxime. To 1 litre of sulphuric acid (1 : 99) add 5 ml. of α-benzoinoxime solution (2%).
Sulphuric Acid–Hydrogen Sulphide. Saturate 1 litre of sulphuric acid (1 : 99) with hydrogen sulphide.

Procedure

Simmer 10 g. of sample (Note 1) in 50 ml. of hydrochloric acid (sp. gr. 1·16) until solvent action ceases. Oxidize the solution with dropwise additions of nitric acid (sp. gr. 1·42) and evaporate to dryness, baking lightly for 20 min. Dissolve the baked residue in 30 ml. of hydrochloric acid (sp. gr. 1·16) and evaporate to a volume of 20 ml. (approx.).

Add 50 ml. of hot water, filter through a paper pulp pad and wash with dilute hydrochloric acid (1 : 19) (Note 2). Dilute the filtrate to 200 ml., cool to below 10° C. and add 10 ml. of ferrous sulphate solution (5%). Stir a little paper pulp into the solution, add a suitable amount of α-benzoinoxime solution (2%) (Note 3), 30 ml. of bromine water, and a further 5 ml. of α-benzoinoxime solution (2%), stirring well between each addition. Allow to stand below 10° C. for five minutes, filter the solution through a Whatman No. 541, 15-cm. paper containing a little paper pulp, and wash six times with cold sulphuric acid–α-benzoinoxime solution.

Transfer the paper and precipitate to the original beaker, add 50 ml. of nitric acid (sp. gr. 1·42), followed by 5 ml. of sulphuric acid (sp. gr. 1·84), and evaporate to fumes of sulphur trioxide. Add nitric acid (sp. gr. 1·42), in 10-ml. portions, evaporating to fumes after each addition, till all organic matter is destroyed (Note 4).

Cool, neutralize the solution by the addition of sodium hydroxide (25%), and add 1·0 ml. in excess. Coagulate any precipitate at 60–70° C., filter through a paper pulp pad, and wash the precipitate six times with hot water.

Dissolve 2 g. of sodium tartrate in the filtrate, adjust the volume to about 200 ml., heat to boiling, and pass hydrogen sulphide for 5–10 min. (Note 5). Acidify with sulphuric acid (1 : 1), adding 8 ml. in excess. Again pass hydrogen sulphide for 5 min., coagulate the precipitate at 60–70° C. and stand for one hour. Filter through a paper pulp pad and wash well with sulphuric acid–hydrogen sulphide solution.

Transfer the filter and precipitate to a weighed platinum or porcelain crucible, dry carefully, heat until the paper is well charred, and ignite at a temperature between 525° C. and 550° C. for 15 min. Cool, weigh the crucible and contents, and record the difference as molybdic oxide (MoO_3, containing 66·66% of Mo).

NOTES

(1) For molybdenum contents 0–0·2%, use a 10-g. sample ; 0·2–1·0%, use a 5-g. sample ; 1·0–2·0%, use a 3-g. sample. Replicate results on a 10-g. sample should lie within ± 0·01% of the true figure ; the limits will increase in inverse ratio to the sample weight.

(2) The residue at this stage may contain molybdenum occluded by tungstic and silicic acids. This residue should be examined as follows :

> Ignite between 525° C. and 550° C., cool, treat with 1 ml. of sulphuric acid (1 : 9) and 2 to 5 ml. of hydrofluoric acid. Evaporate to dryness and fuse with 0·5 g. of potassium bisulphate. Extract with 40 ml. of sulphuric acid (1 : 99), containing 0·5 g. of sodium tartrate. Neutralize the solution with sodium hydroxide (25%), adding 0·2 ml. in excess, heat to boiling and pass hydrogen sulphide for 5–10 min. Acidify with sulphuric acid (1 : 1), adding 2·0 ml. in excess, and again pass hydrogen sulphide for 5 min. Collect the sulphide precipitate on a paper pulp pad, and wash three times with sulphuric acid–hydrogen sulphide solution. Transfer the filter and precipitate to the beaker containing the α-benzoinoxime precipitate before proceeding with the wet oxidation.

(3) The first addition of α-benzoinoxime should be 5 ml. for each 0·01 g. of molybdenum present in the solution.

(4) If there are any signs of a precipitate at this stage the solution must be filtered through a paper pulp pad, and the filter washed with sulphuric acid (1 : 99).

(5) The hydrogen sulphide generator should be capable of providing a rapid flow and the gas should pass through 3 wash-bottles containing distilled water before entering the solution.

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Determination of Vanadium in Carbon and Low-Alloy Steels and Irons

By the Methods of Analysis Committee

SYNOPSIS

Methods of preparing a suitable solution of a sample and of carrying out the determination of vanadium are considered. Cupferron and mercury cathode separation have been investigated, and potentiometric end-point detection has been examined. The interference of alloying elements has been assessed. A recommended method for direct titration finish is described in detail, and tables of vanadium results on specially selected steels are included.

A STANDARD method for the determination of vanadium in steel was required by the Pig Iron, Carbon, and Low-Alloy Steels Analysis Sub-Committee, primarily for the analysis of a series of low-alloy-steel spectrographic standards, but also for the determination of traces of vanadium in carbon and low-alloy steels generally. The constitution of the Sub-Committee at 31st March, 1951, was as follows :

Mr. S. W. CRAVEN (*Chairman*)	I.C.I., Ltd., Alkali Division
Mr. O. BEADLE	Cargo Fleet Iron Co., Ltd.
Mr. W. F. CHARTERIS*	Colvilles, Ltd.
Mr. L. E. GARDNER	Edgar Allen and Co., Ltd.
Mr. C. L. GRAYSON†	English Steel Corporation, Ltd.
Mr. J. M. HARRISON	Lancashire Steel Corporation, Ltd.
Mr. J. D. HILL*	Bragg Laboratory, N.O.I.D.
Mr. J. MCCROSSON†	Lanarkshire Steel Co., Ltd.
Mr. A. W. REED	Consett Iron Co., Ltd.
Mr. N. D. RIDSDALE	Bureau of Analysed Samples, Ltd.
Mr. C. W. SHORT	John Lysaght, Ltd.
Mr. F. SPEED†	Dorman, Long and Co., Ltd.
Mr. H. J. TURNER	Steel Peech and Tozer
Mr. W. WESTWOOD	British Cast Iron Research Association
Mr. J. H. WRIGHT*	Dorman, Long and Co., Ltd.
Mr. J. O. LAY (*Secretary*)	British Iron and Steel Research Association.

* Left 31st March, 1950. † Joined 31st March, 1950.

A bibliography on the determination of vanadium in iron and steel covering the years 1930–1946, prepared by The Iron and Steel Institute, and private communications, including the British Cast Iron Research Association Report No. 184,[1] were consulted in preparation for a research programme.

CONSIDERATION OF METHODS

The Sub-Committee employed the following methods, in some cases with considerable modification suggested by the progress of the experiments :

(*a*) Cupferron separation of vanadium followed by titration of the vanadium
(*b*) Mercury cathode separation of iron and other metals from vanadium, with volumetric finish
(*c*) Potentiometric titration and 'dead-stop' end-point
(*d*) Direct oxidation–reduction titrations.

Cupferron Separation

The sample is taken into solution in sulphuric acid and the vanadium is separated from the bulk of the iron by precipitation with cupferron. After solution of the precipitate, vanadium is determined either (i) by adding excess ferrous ammonium sulphate solution, destroying this excess with ammonium persulphate, and titrating the reduced vanadium with standard potassium permanganate, or (ii) by direct titration with standard ferrous ammonium sulphate using oxidized diphenylamine sodium sulphonate as indicator.[2]

Preliminary tests were made on a mild steel containing about 0·05% of vanadium, but variations between 0·039 and 0·054% of vanadium were obtained, while further trials on a 1% chromium steel (*MGS*/36) and a 5% nickel steel (*MGS*/44) gave 0·34–0·42% and 0·053–0·067% of vanadium respectively.

The sharpness of the end-point was obscured by residual cupferron and difficulty was experienced in ensuring that the reagent was completely destroyed. Also, under certain conditions cupferron can reduce pentavalent vanadium and thereby prevent complete precipitation. Work on the cupferron method was therefore discontinued.

Mercury Cathode Separation

By this method it was hoped to overcome some of the difficulties of the cupferron procedure and particularly that reproducibility might be improved at low vanadium contents.

The procedure was as follows : 10 g. of sample are dissolved in 120 ml. of sulphuric acid (1 : 9) and any residue is filtered off on a paper-pulp pad. The residue is ignited in a silica crucible and fused with a small amount of potassium bisulphate ; the melt is extracted in water and added to the main solution. The solution is diluted to 400 ml. and electrolysed using :

(1) Current of 7–8 amp. (p.d. across terminals about 20 V.)
(2) 950 g. of mercury with a surface area of 50–55 sq. cm.
(3) Platinum gauze anode placed 3–5 cm. above the surface of the mercury.

The mercury is kept in turbulence by a flat-bladed stirrer rotating at 200 r.p.m. and positioned just under the surface of the mercury. Under these conditions

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the electrolyte should be water-white and free from iron after 2½ hr.; it is then run off.

The vanadium is titrated using standard potassium permanganate and ferrous ammonium sulphate solutions with sodium diphenylamine sulphonate as internal indicator.

Typical results obtained by the mercury cathode separation procedure on synthetic solutions are shown below:

Vanadium Added, %	Vanadium Found, %
Nil	Nil
0·02	0·021, 0·019
0·04	0·048, 0·044
0·06	0·061, 0·061
0·20	0·21, 0·21
0·30	0·295, 0·305
0·40	0·395, 0·395

The method was considered satisfactory but since it was rather lengthy and required special equipment it was generally felt that it would be of greatest value for steels containing high percentages of chromium and nickel or low percentages of vanadium. In these cases removal of coloured ions would facilitate end-point detection.

Potentiometric Titration

This method was in regular use by a member of the Sub-Committee and reliable results were also obtained by other members on some low-alloy steels. Further investigation indicated, however, that potentiometric detection of the titration end-point offered no real advantages.

'Dead-Stop' End-Point Procedure

The general principles of the 'dead-stop' end-point procedure are as follows: Two platinum-foil electrodes have an external e.m.f. applied between them by means of a battery and resistances. Shortly after immersion of such electrodes in the solution to be titrated, the current flow through the circuit (as indicated by a micro-ammeter connected in series) falls to a minimum steady value, owing to polarization.

When the titrant is slowly added, the microammeter reading will normally remain steady at first or show a slight creep, but no sudden deflection. At the end-point, however, a rapid and appreciable deflection occurs, believed to be due to depolarization. By back-titration the reading may be returned to its original value and the titration repeated by addition of the original titrant. The 'dead-stop' end-point indication is therefore apparently reversible, and is not affected by the colour of the solution.

The end-point deflection varies with the type of galvanometer and its sensitivity, but response may be improved by suitable amplifiers.[3] The most appropriate value for the applied e.m.f. varies according to experimental conditions and apparatus.

In the determination of vanadium the oxidized vanadium solution was first titrated with *N*/40 ferrous ammonium sulphate solution under these conditions, the applied e.m.f. being about 75 mV.; the back-titration was made with *N*/40 potassium dichromate solution. Blank determinations averaged 0·15 ml. of *N*/40 ferrous ammonium sulphate solution and did not vary appreciably for sample weights up to 10 g.

Typical results obtained by this procedure are as follows:

Electrometric 'Dead-Stop' End-Point Procedure

Analyst	Sample SS1 (0·035% V) Vanadium, %	Sample SS6 (0·36% V) Vanadium, %
(1)	0·036, 0·041, 0·036	0·36, 0·365, 0·365
(5)	0·030, 0·030	0·35, 0·35
(8)	0·029, 0·032	0·37

Effect of Tungsten
(for composition of samples see Table II)

Analyst	Sample MGS/126 Vanadium, %	Sample MGS/127 Vanadium, %	Sample MGS/128 Vanadium, %	Sample BCS/241/150 Vanadium, %
(2)	0·25	0·22	0·19	0·31*
(3)	0·23	0·19	0·175	0·36*

* 5% tungsten steel; end-point not satisfactory.

These results indicate that, except in the presence of considerable amounts of tungsten, satisfactory end-point detection can be achieved by this procedure. In view, however, of the necessity for electrical equipment in this and two of the other techniques hitherto examined, the Sub-Committee felt that attention should be given to a direct chemical method likely to prove of more general application.

Direct Titration Method

Direct titration of vanadium offers the simplest and most rapid means for determination of the element since it avoids the necessity for a preliminary separation from chromium and iron. By using a suitable oxidizing agent, vanadium may be converted to vanadic acid without at the same time oxidizing chromium to chromic acid. Following removal of the excess oxidant the vanadic acid may be titrated with ferrous ammonium sulphate.

In the procedure first examined by the Sub-Committee, solution of the steel was effected in a dilute 1 : 1 mixture of sulphuric and phosphoric acids, and cold potassium permanganate solution was used as the oxidizing agent, the excess being destroyed with sodium nitrite. The nitrous acid formed was then decomposed with urea.

The end-point of the titration with standard ferrous ammonium sulphate solution was determined using the oxidation–reduction indicator sodium diphenylamine sulphonate in the pre-oxidized form. This indicator gives a clearly visible colour change at the end-point and, in contrast to diphenylamine, may be used in the presence of tungsten. With the unoxidized form of the indicator a significant correction may be necessary owing to its reducing action.

Alternative methods of titration were employed (i) by adding ferrous ammonium sulphate solution until the violet colour of the indicator changed to clear green, or (ii) by adding excess reductant and

Table I

RESULTS OBTAINED ON SYNTHETIC SOLUTIONS BY THE DIRECT TITRATION PROCEDURE

Vanadium Added, %	Vanadium Found, %
Nil	Nil–0·005
0·02	0·021, 0·020, 0·021, 0·029, 0·027
0·04	0·041, 0·038, 0·042, 0·048
0·06	0·066, 0·065, 0·064, 0·065, 0·065, 0·054, 0·059
0·10	0·104, 0·105, 0·102, 0·101
0·20	0·18, 0·205, 0·21, 0·215
0·30	0·30, 0·30, 0·295
0·40	0·39, 0·39, 0·395, 0·39, 0·405, 0·39, 0·40
0·50	0·50, 0·51, 0·505, 0·505

back-titrating with potassium dichromate solution to the reappearance of the violet colour.

Results obtained by a preliminary draft of the method warranted a more fundamental examination. This was carried out with a sample of vanadium-free iron and measured additions of standard vanadium solution. The results are given in Table I.

Experience showed that 10-g. samples were unsuitable owing to the colour of the solution and that the weight of sample should not exceed 5 g.

A Study Group was constituted to examine these points and to define more clearly the advantages and limitations of the direct method and its application in the presence of various alloying elements.

EFFECT OF ALLOYING ELEMENTS

The results in Table I indicated that vanadium could be determined satisfactorily in the presence of iron alone by the direct titration method. It was appreciated, however, that salts of elements such as manganese, nickel, chromium, and cobalt could colour the solution in which vanadium was to be titrated and could cause difficulties by obscuring the colour change of the indicator at the end-point.

Tests were carried out by the Study Group using vanadium-free iron with additions of the above four elements, together with measured volumes of a standard vanadium solution. With 5-g. samples and at a vanadium level of 0·05% no interference resulted from the presence in solution of up to 6% of manganese or 6% of nickel, but with more than 1·5% of chromium or 1·5% of cobalt it was increasingly difficult to detect the end-point. In the presence of either of the last two elements it is therefore recommended that the direct titration method should be operated according to the following plan, in which the sample weights are chosen to give the greatest accuracy ; the probable reproducibility limits, as defined by the work of the Study Group, are also indicated :

Vanadium, %	Sample Weight, g.	Max. Limit of Interfering Elements (Cr or Co), %	Reproducibility : Vanadium, %
Up to 0·25	5	1½	±0·005
0·25–0·5	2	4	±0·01
0·5–2·0	1	8	±0·02

In the analysis of low-alloy steels the interference from chromium and cobalt is likely to be greatest in the first range quoted. When the chromium or cobalt exceeds the limits given, vanadium contents below 0·25% may be determined satisfactorily by adjusting the sample weight so that not more than 0·07 g. of either of the former elements is present in the final solution to be titrated by the direct method. The accuracy to be expected will, of course, be correspondingly reduced.

When the interfering elements are greatly in excess of the stated limits, and particularly when very small amounts of vanadium have to be determined with the maximum accuracy, a mercury cathode separation is recommended. The oxidation and titration of the vanadium following electrolysis are carried out in the same way as in the direct titration method.

A separate study of the effect of tungsten was made, since the removal of this element by precipitation may lead to adsorption loss of vanadium, and the use of phosphoric acid as a complexing agent has been stated to cause the formation of a phospho-vanadotungstate, which reacts only partially with the reductant.

Tests carried out by the Study Group (Table II) indicated that the presence of up to 5% of tungsten had little effect in the higher vanadium ranges. Larger percentages of tungsten or sample weights greater than 2 g. appeared to introduce an error because the indicator colour change was less clearly defined.

Sodium fluoride or hydrofluoric acid have been suggested as alternative complexing agents to phosphoric acid for overcoming this difficulty with higher-tungsten steels. These reagents, however, may cause attack on glassware, and the Study Group was not able to obtain a consistently low and reproducible blank when hydrofluoric acid was used.

VARIATIONS OF ACIDITY, INDICATOR, AND OTHER FACTORS

At this stage the Sub-Committee's attention was drawn to a paper by Shaw,[4] dealing with the determination of vanadium in steel, and the Study Group was asked to examine his recommendations and to compare the use of unoxidized and pre-oxidized diphenylamine sulphonate indicator.

The differences between the direct method of Shaw and that already examined by the Sub-Committee were :

(i) Proportion of sulphuric to phosphoric acid in the solvent mixture

(ii) Use of sulphamic acid in place of urea for the destruction of nitrous acid

(iii) Determination of the end-point by back-titration instead of by direct titration of the final solution.

Table II

DIRECT TITRATION PROCEDURE—EFFECT OF TUNGSTEN

	Composition of Steels						Result of Tests: Vanadium, %			
	C, %	Mn, %	Ni, %	Cr, %	W, %	V, %	Analysts (a)	(b)	(c)	(a)*
MGS/126	1·2–1·3	0·2–0·3	...	1·0–1·25	4·0–5·0	0·2–0·25	0·235	0·24	0·24	0·25
MGS/127	0·25–0·30	0·2–0·4	3·0–3·75	1·2–1·4	5·5–6·0	0·2–0·3	0·22	0·215	0·205	0·235
MGS/128	0·50	0·2–0·4	...	1·7–1·9	1·8–2·1	0·15–0·25	0·18	0·175	0·18	0·18
BCS/241/150†	0·23	0·06	...	1·3	5·1	0·385	0·385	0·365	0·375	0·385

* Result after mercury cathode separation

† Synthetic mixture of BCS/241 and BCS/150 in the proportion 1/3

Table III

RESULTS OBTAINED ON TWO SPECTROGRAPHIC STANDARD STEELS BY THE REVISED DIRECT METHOD

Analyst	SS1 (5% Ni Steel) Vanadium, %	SS6 (2·5% Cr-1% Mn Steel) Vanadium, %
(1)	0·040, 0·040	0·365, 0·365
(2)	0·036, 0·036, 0·036	0·355, 0·355, 0·36
(3)	0·026, 0·026	0·34
(4)	0·046, 0·043, 0·045	0·37, 0·37, 0·37
(5)	0·042, 0·041, 0·042	0·365, 0·36
(6)	0·029, 0·029	0·36, 0·34
(7)	0·035, 0·032, 0·030, 0·040	0·34, 0·34, 0·33, 0·345, 0·34
(8)	0·037, 0·034, 0·040,	0·37, 0·38, 0·375
(9)	0·033	0·35
(10)	0·027, 0·027, 0·026, 0·029, 0·029, 0·027	0·365, 0·375, 0·385, 0·36
(11)	0·035, 0·030	0·36, 0·36
(12)	0·040, 0·038, 0·037	0·35
Mean average	0·034	0·355

The Study Group carried out an extensive series of tests on standard steels and synthetic solutions and recommended that :

(i) The concentration of phosphoric acid in the final solution should be increased so as to improve the end-point

(ii) Sulphamic acid should be substituted for urea since the action of the former is more rapid

(iii) Back-titration of the final solution presented a slight advantage in ease of detection of the end-point.

They also reported that unoxidized barium diphenylamine sulphonate indicator could be employed but that it was essential to make a measured addition and to carry out a blank determination for each series of tests, since 0·5 ml. of 0·2% barium diphenylamine solution (unoxidized) consumed about 0·2 ml. of *N*/40 potassium dichromate solution.

These recommendations were confirmed by further work of the Sub-Committee, during which vanadium was determined on four steels by procedures in which all the suggested variations of the direct method were employed. Results in close agreement were obtained as summarized below :

Average Results Obtained by Minor Modifications of the Direct Method (Eleven Operators)

Sample	Vanadium, %	Range of Results, Vanadium, %
SS1	0·033	0·010
SS6	0·36	0·020
SS8	0·65	0·025
MGS/127	0·235	0·030

Table IV

APPROXIMATE COMPOSITION OF SPECTROGRAPHIC STANDARDS

Standard	Si, %	Mn, %	Ni, %	Cr, %	Mo, %	V, %	Cu, %
SS1	0·02	0·21	5·2	0·05	0·2	0·05	0·1
SS2	0·25	0·02	4·1	0·2	0·01	0·45	0·1
SS3	0·2	0·35	2·9	0·35	1·0	0·2	0·5
SS4	0·3	0·5	2·1	0·5	1·3	0·5	0·1
SS5	0·6	1·1	0·55	1·0	1·4	0·25	0·25
SS6	0·15	1·2	0·2	2·3	0·5	0·35	0·2
SS7	0·4	1·4	0·8	1·7	0·3	0·1	0·3
SS8	0·8	0·8	0·05	3·1	0·4	0·65	0·2

It was therefore evident that the contribution of these factors to the spread of results reported was virtually negligible.

FINAL TRIALS

The procedure detailed in the Appendix was now drawn up and tests were carried out on preliminary samples of two of the spectrographic standards for which the method was originally developed ; the results are listed in Table III. These results, representing the first extended trials of the direct titration method, were regarded as satisfactory and warranted the employment of the method for the determination of vanadium in the series of spectrographic standards, the nominal composition of which is given in Table IV. The average vanadium figures obtained are given in Table V.

REPRODUCIBILITY

To obtain a measure of the reproducibility that might be expected when the method was used for referee analysis, it was suggested that a limited number of new samples should be circulated for test, and two steels were selected for this purpose. To ensure that conditions comparable to normal laboratory practice were employed, each analyst carried out a single determination on each sample and reported the figure obtained without duplication or checking.

The composition of the steels and the results reported are given in Table VI. These results were considered to provide satisfactory evidence of the reliability of the procedure.

CONCLUSION

Vanadium may be accurately determined up to 1·0% in steel by the direct titration method recommended in the Appendix. The method has been submitted to the British Standards Institution for

Table V

ANALYSIS OF SPECTROGRAPHIC STANDARDS—VANADIUM, %

Analyst	SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8
(1)	0·035	0·46	0·22	0·515	0·27	0·365	0·12	0·66
(2)	0·036	0·465	0·22	0·515	0·265	0·36	0·13	0·66
(3)	0·026	0·445	0·205	0·50	0·255	0·355	0·10	0·635
(4)	0·045	0·465	0·23	0·54	0·27	0·37	0·14	0·615
(5)	0·042	0·465	0·22	0·52	0·265	0·36	0·10	0·66
(6)	0·030	0·47	0·235	0·525	0·27	0·35	0·125	0·66
(7)	0·034	0·455	0·21	0·515	0·255	0·355	0·105	0·645
(8)	0·027	0·445	0·21	0·51	0·255	0·36	0·105	0·65
(9)	0·033	0·47	0·225	0·525	0·27	0·35	0·11	0·66
(10)	0·029	0·475	0·22	0·535	0·275	0·37	0·12	0·625
(11)	0·033	0·46	0·23	0·52	0·26	0·36	0·11	0·66
(12)	0·038	0·46	0·21	0·505	0·26	0·35	0·115	0·63
Mean	0·034	0·46	0·22	0·52	0·265	0·36	0·115	0·645

Table VI

FINAL RECOMMENDED METHOD (*SEE* APPENDIX)—ASSESSMENT OF REPRODUCIBILITY

APPROX. COMPOSITION OF STEELS

	C, %	Mn, %	Cr, %	W, %	V, %
MGS/154	0·5	0·4	2·0	2·0	0·30
MGS/155	1·0	0·8	0·7	0·5	0·02

RESULTS OF TESTS

Analyst :	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	Average
MGS/154: V, %	0·305	0·31	0·29	0·28	0·305	0·305	0·31	0·305	0·305	0·28	0·295	0·30
MGS/155: V, %	0·025	0·025	0·02	0·015	0·02	0·02	0·02	0·025	0·025	0·025	0·02	0·02

consideration as a standard method for the determination of vanadium in carbon and low-alloy steels.

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APPENDIX

Recommended Method for the Determination of Vanadium in Carbon and Low-Alloy Steels

Solutions Required

Phosphoric–Sulphuric Acid (5 : 3 : 17)—Add 200 ml. of phosphoric acid (sp. gr. 1·75) followed by 120 ml. of sulphuric acid (sp. gr. 1·84), cautiously with stirring to 600 ml. of water, cool, and dilute to 1 litre.

Sodium Nitrate (0·5%).

Barium Diphenylamine Sulphonate Indicator (0·2%)—Dissolve 0·2 g. of barium diphenylamine sulphonate in 80 ml. of hot water, cool, and dilute to 100 ml.

Sulphamic Acid (10%).

Ferrous Ammonium Sulphate (*N*/10 *approx.*)—Dissolve 40 g. of ferrous ammonium sulphate ($FeSO_4.(NH_4)_2SO_4.6H_2O$) in a mixture of 500 ml. of water and 20 ml. of sulphuric acid (sp. gr. 1·84), cool, and dilute to 1 litre.

Potassium Permanganate (0·5%).

Ferrous Ammonium Sulphate (*N*/40 *approx.*)—Dilute 250 ml. of ferrous ammonium sulphate solution (*N*/10 approx.) to 1 litre.

Potassium Dichromate (*N*/40)—Transfer about 2 g. of potassium dichromate to a clean porcelain or silica crucible, heat to fusion, maintain in a fused condition for 1 min., and allow to cool. Dissolve 1·2258 g. of the fused salt in water and dilute to exactly 1 litre (1 ml. of *N*/40 solution ≡ 0·001274 g. of vanadium).

Procedure

Dissolve 5 g. of the sample (*see* Note 1, this page) in 100 ml. of phosphoric–sulphuric acid (5 : 3 : 17) (*see* Note 2). Boil and cautiously add nitric acid (sp. gr. 1·42) until the solution is just oxidized (this should require approximately 4 ml.). Boil to remove nitrous fumes, cool, and dilute to 200 ml.

Add 5 ml. of ferrous ammonium sulphate solution (*N*/10 approx.) to ensure that chromium is all in the reduced state. Add potassium permanganate solution (0·5%) dropwise until a pink colour is produced that persists for at least 1 min.

Reduce excess permanganate with steady dropwise addition of sodium nitrite solution (0·5%), five drops at a time, adding ten drops excess ; add 5 ml. of sulphamic acid (10%), and mix well.

Add exactly 0·5 ml. of barium diphenylamine indicator (0·2%), wait 1 min., then titrate with ferrous ammonium sulphate solution (*N*/40 approx.) until one drop produces no further visible change in colour (*see* Note 3). Add at least 5 ml. in excess and back-titrate with potassium dichromate (*N*/40) to a full violet colour.

Standardization

Place 100 ml. of water in a 600-ml. tall form beaker and run in from a burette 5 ml. of potassium dichromate solution (*N*/40). Add 50 ml. of phosphoric–sulphuric acid (5 : 3 : 17) and exactly 0·5 ml. of barium diphenylamine sulphonate indicator (0·2%). Run in from a burette 10 ml. of ferrous ammonium sulphate solution (*N*/40 approx.) and titrate with the potassium dichromate solution (*N*/40) to a full violet colour. Record the total volume *A* of dichromate used.

Add a further 10 ml. of ferrous ammonium sulphate solution (*N*/40 approx.) and repeat the titration with potassium dichromate solution. Record the volume *B* of dichromate used. Then $A - B$ represents the volume of potassium dichromate solution (*N*/40) required for oxidation of 0·5 ml. of indicator, and this correction (about 0·2 ml. of *N*/40 potassium dichromate solution) must be made to all titration results.

The normality of the ferrous ammonium sulphate is :

$$\frac{B}{10} \times \frac{N}{40}$$

Notes

(1) Quantities of sample and reagents should be adjusted as shown below :

Vanadium, %	Sample Weight, g.	Solvent Acid, ml.
Below 0·25	5	100
0·25–0·5	2·5	75
Above 0·5	1	60

Replicate determinations on a 5-g. sample should be within ± 0·015% vanadium of the true figure.

(2) The limits of interfering elements are as follows :

Sample Weight, g.	Interfering Elements and Limits, % Co	Cr	W
5	1·5	1·5	1·5
2·5	3	3	3
1	8	8	8

For very low vanadium contents a mercury cathode separation is recommended if interfering elements are present in appreciable quantities.

(3) A suitable correction must be made for the indicator blank (*see* section on Standardization).

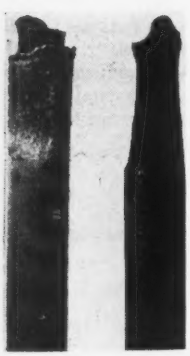
LETTERS TO THE EDITOR

Electrode Economy in Electric Arc Furnaces for Steelmaking

It has been shown[1] that there is considerable variation in graphite electrode consumption for different furnaces, the average figure being about 16 lb. per ton of charged weight. Although this may amount to only a small proportion of the total cost, excessive wear and breakage give rise to production delays, which are much more expensive than the cost of the increased electrode consumption. The reduction of electrode wear, therefore, is of considerable interest to arc-furnace operators.

Excessive electrode consumption is caused by a high rate of oxidation, mechanically weak joints, bad jointing practice (which leads to high electrical resistance and arcing), and dipping of the electrode ends in the slag—although modern rotary-type regulators have reduced this trouble to a minimum. Furnaces using smaller-diameter electrodes, and therefore higher electrode current densities, have been found to have lower electrode consumption figures.[1] This is probably because, when breakages occur, the pieces falling off weigh less than would be the case with larger-diameter electrodes. The Electric Process Sub-Committee of the British Iron and Steel Research Association is studying the influence of physical properties on electrode quality, and also the influence of electrode diameter on electrode consumption. Their results, notably the establishment of a routine acceptance test for electrodes based on resistivity measurements, will be published shortly.

The escape of hot gases through the electrode openings in the roof causes burning of the electrodes at their point of entry into the furnaces. Clearly, all doors and openings in the furnace should be sealed as tightly as possible. Several ingenious devices for sealing the openings around the electrodes have been discussed and applied by the Committee members, but these are not a complete answer to the problem.



The use of thin sheet-metal sleeving on the electrodes reduces the consumption by 10–15%,[2] and future experiments will be made to determine whether a more easily applied sprayed steel coating is equally effective.

Recent B.I.S.R.A. experiments, using aluminium coatings, have been carried out on ½-in. carbon electrodes used on a small laboratory arc furnace melting about ½ lb. of steel. Sprayed metallic aluminium adhered better than paint (which flaked off almost immediately), although after about ½ hr. at steel-melting temperatures the coating was very powdery and came away readily. The graphite underneath was badly pitted, indicating that the covering layers had become porous. When a partially hydrolysed solution of ethyl silicate[3] was applied to the aluminium coating before use (the precipitated silica particles presumably helping to seal the pores), the coating remained hard and adherent, and there was no pitting. The photograph shows the comparison between a coated and an uncoated electrode used simultaneously in the furnace.

Further experiments will be carried out on the larger electrodes used in 3-phase arc furnaces of the normal production type, and on resistor elements used in resistor-heated furnaces. The relative merits of aluminium and other metal coatings, and of silicate ester and other bonds, will be studied.

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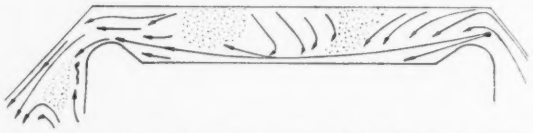
Flow Visualization in Open-Hearth Furnace Models

The value of models for research on open-hearth furnaces is now well established. Air models, which are easy to build, have been used for determinations of velocity,[1] mixing,[2] pressure losses, and refractory wear.[3] Water models are particularly useful for visual work on flow patterns, and the technique of illuminating particles suspended in the stream is well known.[4,5] This technique has now been adapted for use in air models.

Balsa dust, made up of particles smaller than about 30 mesh, may be introduced either into the fuel stream through the burner, or into the combustion air stream. The model can then be illuminated, section by section, and the flow patterns photographed. The light source is a high-intensity carbon arc.

The diagram shows the main features of a typical flow pattern sketched from a photograph. The section was



taken along the vertical centre-line of the furnace. The following features in the flow pattern were easily distinguished by this technique :

(1) The fastest-moving streams of incoming air flow up the end wall, strike the roof, and are deflected down into the furnace chamber. The beginning of the fuel stream is thus not in the fastest-moving parts of the air flow.

(2) In the main body of the furnace a fast-moving stream from the burner flows along the metal surface, rising as it passes over the outgoing ramp. In the upper half of the furnace there is recirculation and down flow, particularly in the region where the ingoing air stream meets this flow.

(3) At the outgoing end the waste gases impinge on the end wall and flow downwards to the slag pocket. This gives rise to a vortex in the slag pocket, from which waste gas is entrained into the stream passing down the end wall. In an appreciable section of the downtake, particularly up the chill wall, the flow is in an upward direction.

The technique has proved useful in establishing flow patterns quickly and easily before making a more systematic investigation of mixing conditions and other problems.

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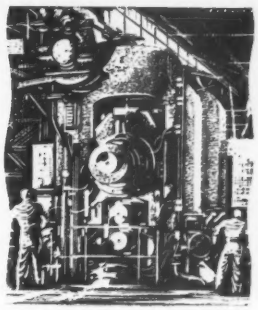
IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE SIXTEENTH MEETING

THE SIXTEENTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, on Tuesday, 4th December, 1951. Mr. C. H. T. WILLIAMS, Chairman of the Group, occupied the Chair.

The MORNING SESSION was devoted to the presentation and discussion of the paper: "Cooling Beds for Bar Mills," by W. UDALL (Brightside Foundry and Engineering Co., Ltd.) (November, 1951, issue of the *Journal*, p. 257).

The AFTERNOON SESSION was devoted to the presentation and discussion of the paper: "Comparisons Between British and American Rolling-Mill Practices," by G. FOSTER (Dorman Long and Co., Ltd.). This paper is printed below, followed by the discussion. The discussion on the paper by Mr. UDALL will be published in the June issue of the *Journal*.

Comparisons Between British and American Rolling-Mill Practices

By G. Foster, A.M.I.Mech.E.

SYNOPSIS

The British Iron and Steel Productivity Team has recently studied American methods with a view to improving British rolling-mill practice. Certain information from their report is given in this paper, and various types of American and British rolling mills are compared.

THE American steel industry has expanded at a phenomenal rate since 1932, and although there has been considerable British expansion during the corresponding period, the British steel industry cannot compete with the American in the matter of size. The average capacity of the modern American plants is almost three times that of British plants (*see* Table I).

It is interesting to note that although the total capacity of American plants has increased by 24,000,000 tons in 20 years, the number of operating plants has been reduced from 163 to 134. The number of very large units is in keeping with the size of the country, and large steel-producing units are accompanied by a corresponding concentration of steel-consuming industries. To deal with small jobbing orders the Americans have developed a network of warehouse companies (some of which are owned by the major steel companies), and the large efficient production units are not expected to handle the small orders so common in British rolling schedules.

The outstanding American development in rolling-mill practice has been the rapid increase in the number and capacity of continuous hot and cold strip mills, and the experience gained during the war in rolling

Manuscript received 12th November, 1951.

Mr. Foster is Development Engineer of Dorman, Long and Co., Ltd., Middlesbrough.

Table I

PLANT SIZE

Capacity Group,* × 1000 tons	Number of Works			
	America		Britain	
	1930	1950	1938	1950
5000–6000	...	1	...	...
4000–5000	1	3	...	...
3000–4000	1	2	...	...
2000–3000	4	5	...	...
1500–2000	7	6	...	...
1000–1500	6	12	...	1
800–1000	5	13	...	1
600–800	16	7	1	4
400–600	11	11	7	7
200–400	20	18	25	21
0–200	92	56	45	47
Total	163	134	78	81
Total capacity, × 1000 tons	65,000	89,200	15,400	18,500
Average size, × 1000 tons	400	665	197·5	228

* Inclusive of the lowest figure in each group

lighter-gauge plates at these mills has focused attention on the semi-continuous plate mills.

There has not been an expansion or improvement in rail or structural mills comparable with the development of the strip mill ; in fact, much of the American equipment is 15 to 25 years old, and some is much older. Improvements have been made, but these are mainly operational and are aimed at easier and faster manipulation of the stock.

SOAKING PITS

The efficiency of fuel utilization in American plants is very variable. In the South and West, where fuel oil and natural gas are freely available, large quantities of blast-furnace and coke-oven gas are wasted, and recuperators and waste-heat boilers are the exception rather than the rule. In the Eastern plants, however, efficient use of these gases is more highly developed, and excellent results are obtained. In both East and West the importance of reducing track times to a minimum is emphasized, and Works Managements keep a very close record of these times.

Primary mills usually work 20 shifts per week, so that there is not the week-end build-up of cold ingots that occurs in this country. In plants where more than one primary mill is fed from a common battery of soaking pits, arrangements are made to stagger mill maintenance shifts so as to maintain continuous operation of the soaking-pit battery. This practice further reduces the percentage of cold ingots to be charged, and also avoids the thermal shock to refractories during the week-end cooling and heating periods.

All four main types of soaking pit were seen during the visits, and the top- and bottom-fired pits appear to be the most economical ; some have consumptions as low as 7 therms per ton. The circular pit has a rather higher fuel consumption, but has an advantage over the recuperator pits in that it heats at a considerably faster rate.

The automatic control of soaking-pit operation is almost standardized, on the following basis :

(i) Automatic fuel flow/pit temperature control
(ii) Automatic air/fuel ratio control
(iii) Automatic pit pressure control.

Most of the soaking pits are operated with coke-breeze hearths.

PRIMARY MILLS

The American policy of developing very large steelworks enables economies to be made, because the primary mills can be loaded to their maximum capacity. For this purpose these mills are often arranged to feed a number of finishing mills. There are at present about 105 blooming and slabbing mills operating in America, and information published by the American Iron and Steel Institute indicates that the average capacity of these mills is approximately 615,000 long tons/yr. More than 30 of these have capacities greater than 1,000,000 tons/yr., and six are rated at more than 1,500,000 tons/yr. The minimum bloom size expected from a primary mill appears to be approximately 7 in. × 7 in., and it is usual to provide either an intermediate blooming mill or a continuous billet mill for sizes below this limit.

In Britain there are 63 slabbing and blooming mills. The average output, excluding the new mill in South Wales, is 225,000 tons/yr. Of these mills, the highest rating is 850,000 tons/yr. Blooming mills in Britain are often expected to roll blooms down to 5 in. × 5 in. or even smaller, and in many plants the blooming-mill output is restricted by the demands of the finishing mill it supplies. When attempting to load the British primary mills more effectively, it is often expected that semi-finished products will be rolled.

The American primary mills are very heavily built to withstand the heaviest shock loads. The roller tables are subject to heavy usage, and the normal practice is to have close-spaced solid forged-steel rollers mounted in roller bearings for the main tables. The rollers are driven through enclosed large-diameter bevels by motors operated under variable voltage control.

Side-guard manipulators are of very rugged construction, capable of withstanding extremely heavy usage yet speedy in operation. Both electrically and hydraulically operated side-guards were seen, and from an operational point of view there seemed little to choose between them.

Roll-neck bearings are of ample dimensions ; they are usually babitted with bronze grid inserts, although a number of mills use synthetic resin bearings with excellent results.

Main drives are usually electric. Steam engines are still in use, however, and if direct coupled, as most appear to be, their rapid acceleration characteristics give performances almost equal to the electric drive. Much thought is given to the disposition of controllers in the mill pulpits, and many mills are operated by only two men.

The very rugged construction of American primary mills enables them to operate continuously under conditions which, by many British iron and steel engineering standards, would be considered misuse of plant, but the total engineering delays in primary mills appear to be no heavier than in Britain.

The fact that American primary mills generally feed to more than one finishing mill makes it difficult to roll in one heat and maintain a continuous feed to the finishing mills while still maintaining the high blooming-mill output required. For this reason, most primary mills discharge into a bloom or slab yard and the material is allowed to go cold ; in many cases inspection and conditioning of blooms is carried out at this stage.

To ensure that the blooming-mill operator, the shearman, and the bloom conditioning yards have good contact with the soaking pit, many excellent communication systems are provided. These transmit written and verbal messages, and are a great help in control and liaison.

STRUCTURAL MILLS

A survey of structural mills in the U.S.A. shows that 22 mills with centres over 20 in. fall into this class ; a rough classification is given in Table II. The predominance of 3-high mills is evident. About 80% of all American joists and beams are rolled in the five universal beam mills, and the size of the mills required to roll the remaining structural sections need be no larger than about 28-in. centres. A mill of this size can conveniently be designed for 3-high operation, and has distinct advantages over its 2-high counterpart. The 3-high mill is faster in operation and more economical in power consumption, and more space is available for adequate entry and delivery guides.

American layouts are arranged so that a maximum of 3 passes per stand is worked, and on many mills only one pass is worked in the last set of rolls. Fewer passes per stand permits better pass distribution and leaves more space between the passes for the provision of heavy entry and delivery guides and various mechanical manipulation devices. Such devices, of which there are many, are an outstanding feature of American mills ; some are simple improvised deflector fences to deflect the stock to the next pass, whilst others are designed to turn the stock as it enters the rolls. For this purpose the entry guides are either spiral twist-up guides mounted on or immediately in front of the entry side guide rest, or are air-operated mechanical turning devices capable of turning the stock through 90° or 180°, in some cases actuated by photo-electric relays. The American roll designer can often make use of the additional roll space to 'cross collar' and so eliminate the necessity of turning the stock through 180°.

The British steelmaker has, in the past, considered the 3-high mill unsuitable for larger structural sections, mainly because of the shock load arising when the stock enters the rolls at speed, and also because of the damage which can occur from a cobble if the guides fail to strip the piece from the rolls, this danger being particularly acute when rolling thin flanged joists. Large-size 2-high mills have therefore been developed in this country ; usually there is inadequate roll space, resulting in crowding of passes in the rolls and leaving little room for satisfactory entry and delivery guides.

Table II

BEAM MILLS IN THE U.S.A. AND BRITAIN

Type or Size of Mill	America	Britain
Universal beam mills	5	Nil
32 in., 3-high	1	Nil
30 in.–36 in., 2-high	Nil	8
26 in.–28 in., 3-high	8	Nil
22 in.–25 in., 3-high	6	
22 in.–24 in., 2-high	2	
20 in. and over, 3-high		2
Total (excluding universal beam mills): 3-high	15	2
2-high	2	8

American sawing practice in structural mills avoids congestion and delay at the saw by hot-sawing orders for long bars only. Any lengths under, say, 40 ft. are cut into standard multiples and are then cut to customers' lengths in the finishing department, by either friction saw, cold saw, or cold shear. Several excellent section shears were seen, most of which incorporate movable side supports to improve the cut when cutting joists or channels.

PLATE MILLS

There has been more development in the American plate mill than in any other section of the heavy industry, although there are still some relatively small capacity units in operation. There are four semi-continuous plate mills operating with an average annual capacity of nearly 600,000 tons. The unit at the Kaiser Steelplant, Fontana, is an example of the present trend. The mill comprises a 110-in. 2-high roughing mill and a 3-high finishing stand in tandem ; plates $\frac{3}{8}$ in. thick or more are finished on this stand and are moved across a cooling bed to a shearing line. Gauges below $\frac{3}{8}$ in. pass to the light mill, which is 86 in. wide and of conventional continuous-strip-mill design. Back-up rolls are 54 in. dia., running in oil-film bearings, and the work rolls are 27 in. dia., running in roller bearings. Stands 1, 2, and 3 are each driven through gear reductions by identical 5000-h.p. motors, and stand 4 has a 3500-h.p. motor direct-coupled to the mill and can deliver up to 2000 ft./min. when rolling coiled plate. The installed h.p. of the heavy mill, including edger rolls at the 2-high roughing, is 15,500. The combined unit has, in all, seven driving motors with an aggregate nominal horse-power of 34,000.

A set of drum-type flying shears is located behind the continuous finishing mill. These shears will deal with a range of lengths from 20 ft. to 62 ft. on a maximum width of 80 in. and up to $\frac{1}{2}$ in. thick. Hot-coiling arrangements are provided, and gauges up to $\frac{1}{4}$ in. have been coiled on down-coilers of the collapsing mandrel type.

The finishing line for plates leaving the 3-high mill consists of a cold leveller, rotary side shears, and end shears. Plates over $\frac{3}{4}$ in. thick are cut at castor beds. As is usual in American practice, only orders for rectangular plates are accepted. The average weekly output of this mill is 11,200 tons when working 20 shifts. The light mill works day shifts only, and on this basis approximately 2000 tons per week are rolled through this mill.

The installation constitutes an excellent example of the present trend in plate-mill layout. However, such a mill unit must be operated at a very high throughput; this will necessitate considerable concentrations if such units are to be used in Britain, and there must be some reduction in the present amount of small tonnage orders and special shapes.

RAIL MILLS

The production of rails in America is concentrated in 11 mills, one of which, at Gary, is a very-high-production single-purpose unit with an annual capacity of 900,000 tons. Of the remaining ten mills, only two are 2-high reversing mills; the remainder are all 3-high or 3-high intermediate and finishing mills fed by a 2-high roughing mill. The American rail production is approximately 2,000,000 tons/yr., indicating that the rail mills are producing only 30% of their capacity in the form of rails, the excess being in the form of billets or 'structurals.' Outputs when rolling rails and billets are in the region of 100 tons/hr., but the output of 'structurals' is considerably less.

The most flexible and popular rail mills appear to be those consisting of a 2-high reversing roughing mill with a 2-stand or 3-stand 3-high finishing train, the first stand of which is located in tandem with a 2-high rougher.

It is not universal practice to reheat blooms, and there is still controversy as to its value. However, reheating at the bloom stage enables the primary mill to produce for other mills in addition to the rail mill, ensures a more uniform rolling temperature, and avoids difficulties in arranging hot-bank practice if the temperature of the rail varies between wide limits. The Americans lay very great stress on hot-bank practice in rail and structural mills.

The 2-high roughing mill of the typical American rail mill is usually equipped with side-guard manipulators, and preliminary forming is done in this stand. The rollers of the table from the roughing to the intermediate mill are shaped so that the piece turns on edge and is supported in this position until it enters the edge groove. The two 3-high intermediate stands and 2-high finishing stand in line have two traversing manipulator tables at each side of the mill, in addition to a fixed run-out roller line from the finishing stand. Three passes are worked in each of the intermediate stands, but only one pass is worked in the finishing stand. Self-operating mechanical manipulators are installed between the outer edge of the traversing tables and the chute pad, and the action of the traversing tables is used to turn the rail through 90° when required. The roll pass layout is skilfully arranged so that the rail is rolled without any direct hand assistance from the mill crew.

Cooling-bank practice is very carefully controlled, in an attempt to reduce the amount of straightening required. A reverse camber is put into the rail in a simple rotary cambering machine located between the saw and hot bank, and the rails are turned by hand at suitable periods during their cooling cycle. So effective is this treatment that there is rarely more than 2 in. of camber in an unstraightened rail, whereas in Britain unstraightened rails with up to 8 in. of camber are frequent. There is no roller straightening of rails in America, and in this respect Britain may be considered to be well ahead.

The majority of American rails are delivered with hot-sawn ends, a practice which would not meet the British specification. The total allowable length tolerance is $\pm \frac{3}{16}$ in. (similar to British practice), and only rails outside this tolerance are milled. This practice gives the American producers a definite advantage, and the reasons for the necessity of milling the ends of British rails should be examined. On the other hand, the American practice of controlled cooling of rails is much more thorough than in Britain, probably because of the higher-carbon rails necessitated by the heavier axle loading on American railways.

BILLET MILLS

American billet production methods are very similar to those in Britain. A fairly high proportion of their production is rolled in continuous mills similar in design and layout to British mills, and, as in Britain, considerable tonnages are rolled in rail or structural mills. These American mills are 3-high, and the use of manipulation devices, including twist-up entry guides capable of entering wide diamonds without manual assistance, increases productivity.

The main difference between the practices in the respective countries appears to be that most American steelworks consume their own billets, whereas British billet producers are supplying to markets made up from the billet requirements of many small jobbing mills, so that their order sheet consists of small quantities of varied sizes, qualities, and lengths.

SIMPLIFICATION AND STANDARDIZATION

In the interests of maximum mill output during the war emergency period, the American Office of Production Management in 1941 surveyed the range of structural shapes offered by the various steel companies and decided that a number of the less essential sizes could be eliminated. The result of the negotiations was a simplified list of structural steel shapes, which has now become the rolling list of almost all mills. A comparison of the sections listed therein with those in the British Standard list reveals some interesting points (*see* Table III).

The figures in Table III exclude the range of universal and broad flange beams, which amount to 47 in America and 11 in Britain. The greater range of universal beams rolled in America reduces the demand on joists and beams, but does not affect the remaining sections. In Britain, however, many sections are very rarely rolled, and are of doubtful value even to the designer. These odd sizes tie up

Table III
NUMBER OF SIZES ROLLED

Joints and I Beams		Channels		Angles		Bulb Angles		Tees	
U.S.A. Mills	British Mills	U.S.A. Mills	British Mills	U.S.A. Mills	British Mills	U.S.A. Mills	British Mills	U.S.A. Mills	British Mills
24	51	29	31	22	43	11	25	12	16

Total for all sections:	U.S.A. Mills	British Mills
	98	166

much capital in the form of rolls, and a reduction in the number of British Standard joists, channels, and angles would be appreciated by the steelmaker, in the interests of fewer rollings of odd sizes.

American standard dimensional tolerances are very comprehensive and leave no room for doubt as to the acceptability of a particular product, so that inspection is simplified and longer runs on any given set of rolls are possible. In Britain there is no comparable list of permissible tolerances, and this is a considerable disadvantage. The standards set in America are easier to fulfil than those set in Britain; they allow of conditioning of plates and structural sections by grinding or chipping and then welding, a practice not allowed in Britain, although it is difficult to understand why. In recent years the standard demanded by customers in Britain has become more difficult to achieve, possibly because of the increased use of welding jigs for fabricated material. A further investigation in America of the effect of the present American standard rolling tolerances on structural design might be very helpful in formulating British policy in this important matter.

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Discussion on the Paper—
SOME COMPARISONS BETWEEN BRITISH AND AMERICAN ROLLING-MILL PRACTICES *By G. Foster*

Mr. **G. Foster** (Dorman, Long and Co., Ltd.) presented his paper.

Mr. **W. A. J. Dinwoodie** (Lamberton and Co., Ltd.): The author has pointed out how the geography, size, and resources of America have affected mill layouts. Britain's situation is such that we are forced to accept some compromises, but it is clear that we should make further attempts to obtain more efficient layouts.

Mr. Foster implied, when he referred to the robustness of American primary mills and their ability to stand up to rough usage, that the British-built ones are light and flimsy. The older British mills may well be, but the modern ones are quite as strong and efficient as their American counterparts. It must also be remembered that capital cost may affect design.

Reference has been made to babbitt bearings and to fabric bearings. I believe that some heavy American reversing mills use roller bearings, and oil-sleeve bearings are also employed. In this country, babbitt bearings without bronze grids are preferred, although fabric bearings have been successfully used. Could the author give some comparative figures of bearing costs per ton rolled for each type of bearing?

In Britain, as in America, main drives are usually electric; steam drives are still in use, but no new reversing steam engine has been installed for about 30 years. It is possible that, in some cases, steam drives might have proved more economical than the reversing electric motor, and there is no doubt that the 3-cylinder 3-crank engine, coupled direct to the mill to be driven, gives reversing characteristics at least equal to those of the electric motor drive of comparable power. The thermal efficiency of the simple 3-cylinder 3-crank engine is low, but when the engine is used as a reducing valve delivering steam to low-pressure thermal generating sets, the overall efficiency of the plant becomes comparable with—and possibly superior to—that of the electric drive reversing motor, when all the losses of the main steam turbine generating plant plus the Ilgner set, etc., are considered. During the war, the Germans put down a 5-cylinder 5-crank reversing engine to drive a heavy armour-plate mill.* This surely indicates that they do not consider the reversing steam engine for heavy mill drives to be out of date. I personally think that it is the best from the point of view of strength and robustness.

The difference between British and American mills for heavy structural sections is striking. The practice in this country, and to a considerable extent in Europe, is to use 2-high reversing mills from, say, 24 in. to 36 in. dia. Although the cost of reversing drives is higher, with a properly designed installation and allowing for maintenance costs on rolls, tilting tables, etc., the 2-high set-up should not be inferior to the 3-high. More information from the author on this subject would be welcome.

* J. A. Kilby and W. G. Cameron, "Recent Developments in Steel Processing," 1947, Institute of Engineers and Shipbuilders in Scotland.

Mr. Foster said that Britain is well ahead in regard to the roller straightening of rails and heavy sections. There are about six heavy roller straighteners working in Britain today, and at least two more are being built for the North-East coast. A modern straightener with properly designed tables, banks, and handling facilities has a high tonnage throughput and low labour costs. I hope America will copy this practice.

Mr. **G. Foster**: I agree with Mr. Dinwoodie that we in this country should not build our new mills on the assumption that we are going to accept small lot orders and roll a very wide range of products; we should instal specialist mills, and fewer of them.

In regard to mill construction, the best of the new British primary mill installations are undoubtedly as good as the American mills, but there are too few of them and too many were designed before 1914.

On the question of steam *versus* electric drives, most steel companies have gone to very great lengths to compare these drives, and at least one of them showed that the steam engine was slightly better; this company, however, ultimately installed an electric drive.

In connection with Mr. Dinwoodie's remarks on 2-high and 3-high mills, I tried to show in the paper that at least one of the reasons for the development of 3-high mills in America is the fact that 80% of the joists and beams are rolled on the Grey type or Puppe type broad-flange beam mills, thus relieving the structural mills of awkward thin-flanged joist sections. I agree that well-designed 2-high layouts, with more stands and drives available and with more space for good guide tackle, could be very efficient units.

When I stated that American cooling-bank practice is much better than that in Britain, I was referring to our heavier-type cooling banks, where the products are usually bunched together and are sometimes lifted from the cooling banks while far too hot, eventually reaching the straightening machine in a very poor condition. Very great care is taken in America when handling products in the hot state; the cooling banks are of ample capacity and greatly reduce the danger of damage to products between the saw and straightening machines. The Americans often go to extreme lengths to keep bars separate from each other to ensure even cooling, and the straighter condition of the products lifted from the cooling bank mainly accounts for the fact that their down-presses and straightening facilities generally achieve much greater outputs than our equivalent machines. The need for high-production roller-straightening machines is therefore not so apparent as in Britain.

Mr. **E. T. Sara** (The United Steel Companies, Ltd.): I should like to underline what the author has said about reducing the number of small orders on which British mills must depend. Customers must be encouraged to place larger orders, by a rearrangement of the pricing system to make large orders cheaper and small orders dearer—compulsion, even if possible, is undesirable. This is not a simple matter, and the extent to which it can be done will depend on the rearrangements in the mills.

Mr. **W. W. Franklin** (Davy and United Engineering Co., Ltd.): Mr. Foster stated in reply to Mr. Dinwoodie that mills equivalent to American ones are not available in this country. I would like to point out that four new blooming mills and one slabbing mill have been installed in Britain during the last few years; another slabbing mill is in course of installation now, and still another is being designed. These blooming mills—as blooming mills only, not slabbing mills—have cross-sectional areas of post of about 450 sq. in., and the slabbing mills have cross-sectional areas of post up to 650 sq. in., compared with the figure of 600 sq. in. mentioned in the paper. All these mills have Ward-Leonard control on the screwdown gear, with speeds up to 250 in./min. with motors up to 150–200 h.p. The chocks and roll-housing windows are generally designed for easy withdrawal of the rolls, so that both rolls are removed simultaneously, thus reducing roll-changing time to a minimum.

Roll-neck bearings of white metal with bronze grid inserts have been used in this country for many years, but are gradually being replaced by anti-friction bearings. Excluding the new mill in South Wales, which is on roller bearings, one slabbing mill already operating in this country and another at present being installed are both operating on oil-film bearings. Roller tables all have solid forged-steel rollers and there is Ward-Leonard control on the main ingoing and outgoing tables at the mill. More roller bearings are now being used on mills in this country, and the latest installations are being equipped with roller bearings throughout the tables. Opinion is still divided on the use of roller bearings on, say, the main tables of a blooming mill, but by correctly designing the mounting of the bearings no troubles are expected to arise. Again, main tables and breast rollers nowadays are always put under Ward-Leonard control.

Manipulators are in the same category as the mills and are all of extremely heavy construction, to stand the rough usage, but with speedy operation. Welded construction is being used to a great extent on both the manipulator heads and the main roller-table frames. This construction reduces the weight of the parts but maintains similar strength to that obtained with steel castings. Also, particularly in roller tables where circulating oil lubrication is used, fabricated construction lends itself more readily to the design necessary for oilways, etc.

Today, heavy slabbing mills are usually installed with twin-motor drives, thus eliminating the pinion housing; in this case the mill spindles are up to 30 ft. long and the maximum angle of inclination is less than the 8° mentioned by Mr. Foster. I think, therefore, that the modern blooming mills in this country are comparable with the American blooming mills, and that, in certain features, the British blooming and slabbing mill has advantages over the American blooming mill. For example, many American universal manipulator heads do not extend to the mill rolls—nearly all of them stop short at the face of the housing. All the British manipulators, on the other hand, carry the head right up to the blooming-mill roll, which allows better guiding, particularly with a short ingot. In this respect, therefore, British practice is probably better than American.

In regard to 2-high and 3-high mills, has the author any figures to show the relative cost per ton of material produced? A 3-high mill may have a greater output, but I think the roll costs per ton must be greater; the maintenance costs, also, would be greater if they included the elaborate travelling tables normally used on this type of mill.

Mr. **Foster**: I agree with Mr. Franklin's remarks, and have tried to convey that the new British heavy mills are quite as good as the American; but I do not think the outputs from more than two of the four new blooming and slabbing mills installed in this country since the war are equivalent to the capacity of the *average* American blooming mill. The American primary-mill capacity, averaging old and new mills together, is 615,000 tons/yr.; our highest figure, excluding the South Wales mill, is 850,000 tons/yr., the average capacity being only 225,000 tons/yr. Whilst I agree that the British mill design is equally as good as the American, the production from the British mills does not appear to equal the production from the American mills. In many cases this is the result of limitations outside the primary mill

itself. Most of the new American primary mills produce at least 1,000,000 tons/yr., and very many of the older mills have similar outputs.

We in this country think that it is necessary for the manipulator heads to go up to the rolls, to guide short ingots and to guide and support the stock better when rolling smaller sizes. The Americans do not expect their primary mills to roll small sizes, and do not need the extension to the manipulator heads.

Unfortunately, I have no information on the relative production costs of 2-high and 3-high mills.

The **Chairman** (Mr. **C. H. T. Williams**) : Has Mr. Foster considered the increased production obtained in America as a result of the longer working week ? In most of the American primary mills 20 shifts are worked, in many cases almost continuously for the 8 hours of each shift ; in this country the shift is 7½ hr. and there is a maximum of 17 shifts. The American production is therefore more than 20% greater from the same type of unit, for this reason alone.

Mr. **Foster** : This is a point to be borne in mind. The Americans arrange their rolling-mill operations without stops for meals, and so do not lose the half-hour which is lost in this country. Moreover, their arrangements are such that they can work 20 shifts per week, which we in this country are not allowed to do. The American mills thus have greater capacity possibilities than ours.

Mr. **F. E. Probyn** (Richard Thomas and Baldwins, Ltd., Ebbw Vale) : The mill with which I have been associated at Ebbw Vale for the past 13 years is a duplicate of the Ford mill in Detroit. Our experience confirms Mr. Foster's remarks about the rugged strength of the American rolling mill, but the cost of maintaining the roller tables and manipulators is high. Despite this, the average mechanical delays on this mill are 2%, which compares favourably with American practice.

Modern standards of sealing and precision gear setting would seem to demand the use of roller bearings on these heavy roller tables. The high-speed screwdowns in slabbing mills give rise to brake trouble, and we have found it necessary to increase the size of our brakes from 26 in. to 30 in. dia. Many mills use three brakes on the twin-motor drives, to prevent back-screwing when the mill is under draft. We obtain better service from our lead-antimony lined roll-neck bearings if we leave out the bronze inserts and rely solely on the white-metal lining.

The Salem soaking pits at Ebbw Vale are equipped with 8 ft. 6 in. waste-heat boilers, 2 pits to a boiler, which steam at 150 lb./sq. in., with a nominal capacity of 10,000 lb./hr. The actual performance of 5 boilers yields about 4,000,000 lb. of steam per week for general use in the plant, which is a useful figure in view of the fact that low-pressure steam costs 4*s*. 6*d*. per 1000 lb.

Continuous reheating furnaces necessitate the use of water-cooled skids, and these can be very troublesome. The study of many failures has shown that much trouble can be avoided if certain precautions are taken. The round skid bead and the heavy solid-drawn pipe should be of the same grade of best open-hearth steel, and should be stress-relieved after joining with continuous welding. We find that the best support is obtained by the use of water-cooled cross-pipes with vertical pipe supports resting on the furnace bottom. When the skid pipes are supported on refractory walls the incidence of failure is high, but we are not sure why this is so. Following this, we materially shortened the skid support walls during the recent 20% increased capacity reconditioning of the three 60-tons/hr. slab reheating furnaces.

The author mentions the importance which the Americans attach to relating man-hours to tonnage. Unfortunately, in many instances in this country the value of mechanization has been lost by over-manning, and we should follow the American lead in this field.

Mr. **Foster** : The Americans are still undecided about using roller bearings for heavy mill roller tables, and my impression is that, of the new installations, the preferences for plain or roller bearings are about equal.

The high-speed screwdowns in American primary mills have the braking troubles which Mr. Probyn has mentioned, and they get over-running due to the high inertia, with the resulting difficulty of setting on a mark. The higher the gear ratio between the motors and screw, the more is the need for efficient braking to prevent back-screwing when the mill is under load.

The use of bronze grid inserts in babbitt-lined roll bearings seems rather controversial. We in my Company do not use the inserts but prefer, like Mr. Probyn, to allow the babbitt metal to take the full load. However, at least two of the modern British blooming mills which Mr. Franklin mentioned have roll-neck bearings with bronze grid inserts. My own view is that these should be avoided if the bearing area can be arranged to take the load without spreading the babbitt metal. Most of the bronze grids originate in efforts to avoid the babbitt metal spreading over grease-supply apertures.

The remarks on waste-heat boilers applied to soaking pits are interesting. The Americans use them in the Eastern part of the country, where fuel economy is more important than in the West.

The use of water-cooled steel tubes in continuous furnaces at Ebbw Vale agrees with the American practice, which is similar to British except that in the hearth area the Americans use plastic rammed material.

I note with interest Mr. Probyn's remarks on the value of American man-hour/ton figures, which are so carefully prepared and so very much used in Management. The American job evaluation scheme, where each job is listed in the works' records, is very valuable. Very few men in American steelworks are loosely scheduled as, say, 'mill labourer' ; everyone has a particular job and is rated accordingly. This enables the Management to keep a closer control of manning lists and to maintain man-hours/ton at a minimum, and I feel we should copy the American practice in this respect.

Mr. **N. C. Lake** (The Head Wrightson Machine Co., Ltd.) : Mr. Foster referred to air-operated twist guides which are arranged to turn through 90° and through 180°. Has this type of twist guide been applied to 3-high mills where the pass sequence requires both 90° and 180° turns in successive passes ? If so, how do the mill operators select the angle through which the twist guide must turn as the air-operated manipulator moves across the face of the rolls ?

To shear sections—angles, channels, and joists—it is necessary to have shaped blades, and the need for accurate positioning of the sections to enable them to pass through the shear can give rise to difficulty. Can the author tell us what arrangements the shears have for cutting sections, and whether they are upcutting and downcutting shears ?

I understand that the rotary flying shears which are used to cut up the plates from the multi-stand finishing mills are the limiting factor in the output of plates from a semi-continuous strip mill, and that the speed of these shears is much lower than the normal rolling speed of the mill. Would the author please confirm this. I believe the Americans are contemplating eliminating flying shears on continuous mills to a very large extent, and using instead coils of much thicker material, taking these coils through processing lines of uncoilers, levellers, edge trimmers, flying shears, and finishing levellers. This would increase the productivity of the hot strip

mill, because there would not be the limitation of the flying shear speed at the hot mill.

In defence of the British blooming mill, surely the output of the blooming mill is a function of the work being done on the blooming mill? We may do more passes in this country and make smaller blooms than is the practice in America, and this would have an effect on productivity.

I was interested in Mr. Foster's remarks on 2-high and 3-high mills, and would like to know if the larger 3-high American mills have tilting tables on both sides of the mill. I have heard arguments in America in favour of tilting tables on one side only; the author's opinion on this and on the merits of traversing tilting tables compared with non-traversing tables, would be interesting.

Mr. **Foster**: The majority of the 3-high mills that we saw in America had traversing tables, and I thought some would have been better with fixed roller tables. Traversing tables limit, to a certain extent, the number of pieces that can be on the floor simultaneously. The heavier 28-in. mills generally have tilting tables at both sides of the mill, and the delivery side table is arranged to be in the upward position to take the shock of the bar falling from the top/middle pass.

We saw only one set of mechanical twist-up entry guides in operation and many of the spiral type, and I doubt whether it would be possible to use the type of manipulator shown in Fig. A to turn through 90° and 180° in the same stand of rolls. The American mill layouts and roll-pass designs with fewer passes per stand are arranged so that such a facility is unnecessary.

The section shears I referred to were of the down-cutting type and used shaped blades, most of them cutting a piece approximately $\frac{1}{2}$ in. long out of the section. When cutting joists and channels, hydraulically operated side supports avoided any tendency for the flanges to splay outwards during cutting. The shears were provided with a short lifting table to lift the piece and allow it to run through the shear clear of the bottom blade, both blades being shaped to suit the inner profile of the joist angle or channel.

The rotary shear at Fontana is designed to cut at 2000 ft./min., the maximum delivery speed of the mill, and I have no information to suggest that it is unable to do so; I cannot imagine a light plate mill requiring a faster delivery rate than 2000 ft./min.

Mr. **J. Beese** (Richard Thomas and Baldwins, Ltd., Ebbw Vale): The author has referred to the excellent service given by rammed plastic refractory hearths in the soaking zone of continuous reheating furnaces. Many hearths of this type have been used in the slab reheating furnaces at Ebbw Vale; these hearths were made from materials supplied by British and American refractory makers, and we understand that our tonnage figures in relation to hearth life compare favourably with the American figures. However, some of the disadvantages of plastic hearths should be mentioned. The removal and renewal of this type of hearth in the confined space of the soaking zone is a slow and laborious process, and to do the job the furnace may have to be stopped. Also, slag frequently amalgamates with the hearth, so that the slab-furnace operating crew are obliged to remove chunks of hearth to get rid of the slag. The hearth therefore assumes a hill and valley contour, and this leads to slag piling-up in the soaking zone, which is a difficult problem to deal with.

The necessity of burning-in the hearth at a temperature of about 2600° F. for 30–40 hr. has sometimes been partly responsible for the failure of the soaking-zone roof, especially around the thermocouple. In these circumstances we have had to reduce the burning-in temperature, to prevent more serious damage to the

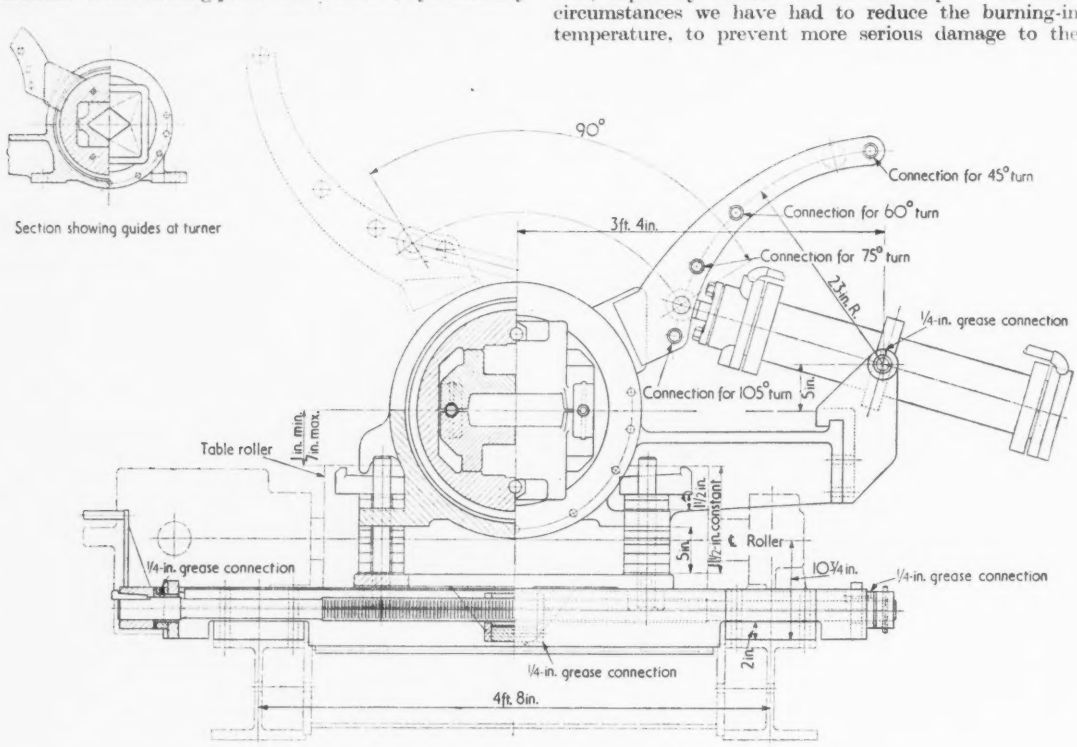


Fig. A—Arrangement of billet turner

roof, and this has meant accepting an inferior hearth that is liable to push out in a matter of weeks. Accordingly, we have installed a 73% alumina brick hearth reinforced with six rows of heat-resisting steel skids. During ten consecutive weeks, 76,000 tons of slabs have passed over this new type of hearth, with negligible wear on skids and bricks—a much better performance than that of the rammed hearth. In our opinion, the advantages of the alumina brick hearth over the rammed plastic hearth are as follows: (i) It does not require burning-in; (ii) it is installed in less than half the time; (iii) the slag does not amalgamate with the brick, and consequently the removal of the slag from the hearth is a short and simple job, compared with the long and difficult job of 'slagging' the rammed type; (iv) the brick hearth can obviously be patched fairly easily if and when required. I understand that these hearths are used in America—did the author see them there?

Mr. **Foster**: Your experience with steel skids in continuous furnaces agrees with mine. We have bloom furnaces working under similar conditions, and find that the hearth prepared in the manner you described requires no burning-in; our experience, however, is that slag does amalgamate with the brickwork, leading to difficulty during week-end slagging operations. Nevertheless, this type of hearth gives good service.

On the question of plastic ramming in the hearth area, Dr. Marshall is better able to give the required information.

Dr. **D. F. Marshall** (The Park Gate Iron and Steel Co., Ltd.): Generally speaking, American slab or billet reheating furnaces have plastic hearths and water-cooled or heat-resisting steel skids. Recently, trials have been made of silicon carbide grids and also of heat-resisting steel grids built into the hearths, and the former are considered to be very promising.

Although American furnace hearths are by no means trouble-free, they do give a fairly good performance. There are two main reasons for this. Firstly, the rate of scale or cinder formation is kept at a low level by the widespread use of fuel/furnace-temperature automatic control linkage, fuel/air ratio automatic control, and automatic furnace-pressure control. This type of equipment gives very close control over temperature and atmosphere conditions in the hearths. Typical controlling temperatures range from 1150° C. for steels containing more than 0·75% of carbon, to 1250–1300° C. for low-carbon steels. Secondly, regular attention is given to hearth maintenance, usually by means of special tools fitted to the discharge pusher gear. These tools are designed for digging, levelling, or scraping.

Attention is given to the hearth much more frequently than is usual in British practice; in some plants it amounts to shift-by-shift conditioning.

Mr. **R. Stewartson** (The United Steel Companies, Ltd.): I should like to examine, in further detail, the reasons for the high production in American blooming mills. We should bear in mind that about a quarter of the total tonnage of ingots made is produced for subsequent rolling into strip. Thus a fairly large proportion of the primary-mill output, particularly in the more modern high-capacity mills, is in the form of heavy slabs, which may be 30 in. × 4 in., *i.e.*, 120 sq. in. section, or bigger, compared with the 50 sq. in. of a 7 in. × 7 in. bloom. The amount of work required to reduce a large ingot to a heavy slab is much less than for blooms, and heavier ingots can be used without the product becoming too lengthy, so that large outputs can more easily be achieved.

Using the A.I.S.I. figures for 1948 as a basis, it appears that, of the more than 30 mills stated to have an annual capacity of over 1,000,000 tons, all except five are slabbing mills working in conjunction with strip mills, and are therefore not directly comparable with British mills rolling 5-in. or 7-in. blooms. This does not mean that production in some British mills cannot be improved, but I do feel that tonnages in many of our mills compare favourably with American mills producing similar products. For example, the capacity of the 40-in. mill at Wisconsin steelworks, which is of modern design and rolls blooms only, is given as 620,000 British tons. On the other hand, there is the fairly old 44-in. mill at Aliquippa, which I am sure the author has included in the five mills said to produce more than 1,500,000 tons/yr. This remarkable mill rolls blooms only, from 4½-ton ingots, at the rate of one ingot per minute, *i.e.*, about 1500 tons per shift; the mill is steam-engine driven.

An analysis of detailed operating figures shows that most American plants are set up to work 20 shifts per week, and in practice average about 19 shifts, allowing for odd shifts to cover cumulative maintenance. Taking this figure of 19 shifts as the average working week, a blooming mill would have to work about 1000 shifts, rolling 1000 tons per shift, to produce 1,000,000 tons/yr. A cogging mill at one of the branches of my Company, rolling 7 in. × 7 in. blooms from 3¾-ton ingots, is producing very nearly 1000 tons per shift, and I contend that this mill, which is of typically modern British design, is therefore more than equivalent to the 1,000,000-tons/yr. American mill.

It has been said that 20-shift working has the disadvantage that one down-shift a week does not give a great deal of time to carry out thorough maintenance. However, a 40-in. blooming and slabbing mill at Pittsburgh rolled 915,000 (British) tons of slabs and blooms in the first nine months of 1949, with only 37 down-shifts, *i.e.*, four per calendar month. I believe that, in trying to improve our production, our aim should be to work more shifts each week and to attempt the rolling of heavier products.

Mention has been made of the thorough treatment of American rails. As the author has stated, they have a much higher carbon content (about 0·95%) than ours, and I am sure that the careful cooling treatment is not necessary with our medium-carbon rails. Are British rails, with their rather high manganese content, as good as American rails, from the point of view of wear? The American standard rail length is only 39 ft., which facilitates handling, slow cooling, and transporting to special cooling places; a 60-ft. rail, which is the standard in this country, would perhaps be rather more difficult to handle.

I am very much in agreement with the author's remarks about the end-milling of rails. I had understood that some American plants end-mill a large proportion of their rails, whilst others never do it at all. At one plant, for example, the end-milling machine was a first-world-war relic, only used for end-milling odd rails. I am pleased that Britain is ahead in the use of the roller straightener, but I should like to ask the author whether he thinks the Americans could use roller straighteners on their rails, in view of the fairly high carbon content.

One clever feature of American rail practice is the rotary stamping machine for marking rails as they leave the hot saw. This would not cost much to copy, and might save man-power.

The author has mentioned dimensional tolerances, which is an important subject in these days. For alloy and carbon merchant bars, a standardized tolerance system would be most desirable and a great help to our small rolling mills.

Finally, I believe that some of the air-operated manipulators have movable stops to limit the travel to either 45°, 90°, or 180°.

Mr. **Foster**: It is true, as Mr. Stewartson pointed out, that the American slabbing mills attached to the hot strip mills increase the average American blooming and slabbing mill output. Even so, if we were to compare only the information on the American blooming mills with that on British mills, we should find that the American mill is very much ahead of the average British mill. Mr. Stewartson has referred to the fact that one British blooming mill rolls approximately 1000 tons per shift. This is the highest production of any blooming mill in this country; moreover, within the same steel company there is an almost identical blooming mill which is rolling very much less than 1000 tons per shift, because there is not enough finishing-mill capacity to absorb the blooms it produces. We must endeavour to group our finishing mills around high-capacity blooming mills, even though this means more drastic concentration of our steel production than we have yet attempted.

I discussed the slow cooling of rails mainly to show the effects of the straightening practices. Although there may be very little need to slow-cool rails in Britain, owing to the lower carbon content, I am certain that if we were to adopt the American practice of careful handling of rails on the cooling bank, we would have very much higher outputs from the straightening facilities and fewer broken rails.

The Americans are actively interested in the roller straightening of rails and have already contacted this country for information regarding British machines. They are confident that they can roller-straighten their rails, and I think they will be doing so in a few years.

In regard to the end-milling of rails, our information is that the American railways allow hot-sawn ends, but the total tolerance of $\pm \frac{3}{16}$ in. is rather difficult to achieve in hot-sawing practice, and about 10% of the rails are end-milled simply to get them within this tolerance.

The rotary stamping of rails is very much simpler, and saves a great deal of man-power. It could be copied in this country, provided that there was a length of track between the hot saw and the cooling bank. Most of the British rail mills have the hot saw on the edge of the cooling bank, and the rail must be side-transferred immediately it leaves the saw. All the American rail mills have room for at least one length of rail between the saw and the cooling bank. While one rail is being sawn against the stopper, the other is being passed through a rotary cambering machine and at the same time is being hot stamped. It is often very difficult to conveniently position rotary cambering and stamping devices in existing British rail-mill layouts.

I agree with Mr. Stewartson's remarks on tolerances, and feel strongly that we should introduce standard tolerances. These would do much to clarify the position, and would avoid negotiation, and often argument, between customer and producer.

CORRESPONDENCE

Mr. **A. H. Norris** (John Lysaght (Scunthorpe Works) Ltd.) wrote: I was surprised to note the limits of 1250° C. to 1340° C. in the soaking-pit temperatures listed in the paper. The 1340° C. limit seems very high, particularly as the temperature is presumably recorded through a thermocouple in the wall. In my Company we have a very modern battery of soaking pits, and the maximum temperature recorded is 1270° C. Admittedly we do not roll any Armco ingot iron which would require a higher temperature, but I am interested to know whether the author considers that the Americans heat their ingots to a higher temperature than we do in this country.

Do the Americans continue to use the hot scarfing machines in their billet mills as much as they used to a few years ago? There seems to be a divided opinion in this country as to their usefulness, and this may also apply in America.

In many of our continuous mills it is customary to use either steel-base rolls, alloy indefinite chill rolls, or alloy chill rolls. I was interested to learn from a member of a continental billet mill that they proposed to use mainly steel rolls. Has the author found any tendency in this direction in America?

The author referred to several excellent systems of communication in the American mills, and I would be glad if he could outline what, in his opinion, was the best system.

Mr. **R. S. James** (Thos. Perry, Ltd.) wrote: Did Mr. Foster form any opinion as to which particular type of heavy plate mill is considered most successful in America, the 2-high reversing, 3-high, or 4-high reversing?

Mr. **J. McCracken** (Colvilles, Ltd.) wrote: Mr. Foster states in his paper that plates $\frac{3}{8}$ in. or more thick are finished on the 3-high mill. Why is this—that is, why should the continuous stands be kept idle while plates $\frac{3}{8}$ in. up to, say, $\frac{1}{2}$ in. are finished on the 2-high and 3-high mills? It may be that the shearing line is unsuitable, but perhaps there are other reasons. I am informed that at the South Chicago works the continuous stands are used for all thicknesses of plates, even for odd lots. Can Mr. Foster say if this is correct?

AUTHOR'S WRITTEN REPLY

Mr. **G. Foster** wrote in reply: The temperature limits quoted do appear rather high, but when comparison is made with British practice due allowance must be made for the position of the thermocouples in the soaking pit. The temperature of ingots being rolled in American mills seemed similar to our best practice.

I have no reliable evidence of American opinion on hot-scarfing machines, but we saw a number that had been idle for a long period.

The American roll-shop foremen still prefer to use iron rolls if they are strong enough to withstand the rolling pressure. They do, however, specify widely differing qualities of both iron and steel rolls, according to the type of service expected from them. In this respect the American roll superintendent tends to accept the responsibility of specifying roll analysis much more freely than we do. Each appears to have his own preferences.

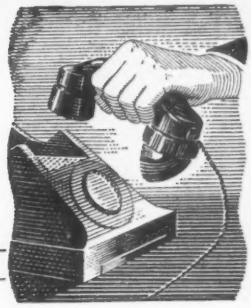
My knowledge of American communication systems is not sufficient for me to be able to outline any of them.

Apart from universal plate mills, of the 21 mills operating in America only one is purely 2-high. However, even this preference for 3-high or 4-high operation seems to be giving way to the flexible semi-continuous mill possessing high output capacity.

There appears to be no reason why gauges up to $\frac{1}{2}$ in. should not be rolled through the continuous train at Fontana. The output of this semi-continuous plate mill is, however, controlled by the capacity of the combined slabbing and blooming mill that feeds it. On gauges $\frac{3}{8}$ in. and above, I would expect the 2-high and 3-high mills to be able to roll all the slabs available and to produce a thoroughly satisfactory plate without the cost of operating the continuous train.

The continuous plate mill at South Chicago consists of three continuous roughing stands driven from a single 4000-h.p. motor, preceded by a scale breaker, and followed by six 4-high continuous stands with 52-in. backing rolls, capable of rolling a 96-in. wide plate and driven by separate 3500-h.p. motors. All products receive single passes, making a total of nine passes. The maximum delivery speed is only 870 ft./min. compared with the 2000 ft./min. at the Fontana mills, and I would be tempted to hazard a guess that the mill does not roll too many light gauges.

N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Meetings

The **Annual General Meeting** of the Institute is being held on Wednesday and Thursday, 30th April and 1st May, 1952. The programme was given in the News Section of the April issue of the *Journal*.

Meeting in Swansea. A meeting of the Institute will be held in Swansea from **7th–10th October, 1952**. The programme will include visits to works in South Wales, and special arrangements will be made for Ladies. Details of the programme will be announced later.

The **Autumn General Meeting** of the Institute will be held in London during the second half of **November, 1952.**

Richard Elsdon

The Council have resolved that Mr. Richard Elsdon should be nominated to be an Honorary Member of the Institute, in recognition of his valuable services as Librarian. It is also proposed that a portrait of Mr. Elsdon should be painted and hung over the fireplace in the Library at 4 Grosvenor Gardens.

NEWS OF MEMBERS

▶ Mr. D. V. ATTERTON has been awarded the Ph.D. degree of the University of Cambridge.

▶ Dr. E. C. BAIN has left the Carnegie Illinois Steel Corporation to take up an appointment with the United States Steel Company, Pittsburgh, U.S.A.

▶ Mr. G. J. BANNER has left the Aston Chain and Hook Co., Ltd., Birmingham, to join Messrs. Eva Bros., Ltd., Manchester.

▶ Mr. C. BARSTOW has graduated from the University of Leeds and is now a Research Assistant at the University.

▶ Mr. J. D. BOLCKOW has been appointed Works Manager of Messrs. Redpath Brown and Co., Ltd., Edinburgh.

▶ Mr. J. E. BOWERS is now at the Department of Chemical Engineering, University of Cambridge.

▶ Mr. R. F. BOWLER has left the British Iron and Steel Research Association to take up an appointment as personal assistant to the Development Engineer, The United Steel Companies, Ltd., Rotherham.

▼Dr. W. F. CHUBB, Professor of Metallurgy at King Fouad I University, Cairo, Egypt, has taken up an appointment with Messrs. D. P. Fisher, Ltd., Wellington, New Zealand.

▶ Mr. P. W. CLARK has been awarded the Ph.D. degree of the University of Sheffield, and is now with the Derbyshire Silica Firebrick Company.

▶ Mr. F. M. DAVIS has left Messrs. Swan, Hunter, and Wigham Richardson Ltd., Wallsend-on-Tyne, to take up an appointment as Metallurgist at the Sunderland Factory of the Bristol Aeroplane Co., Ltd.

▶ Mr. F. C. DIXON has taken up an appointment with Mackenzie Engineering, Ltd., Bosnia, Yugoslavia.

▶ Mr. C. DUNGER has left Dorman Long and Co., Ltd., Middlesbrough, to take up an appointment with De Havilland Propellers, Ltd., Hatfield.

▶ Mr. A. ENGLISH has taken up an appointment with A. G. McKee and Co., Cleveland, Ohio, U.S.A.

▶ Mr. A. J. GRAHAM, O.B.E., has resigned from his position as Technical Controller with Messrs. Sandberg Consulting and Inspecting Engineers.

▶ Mr. D. M. GROUND has joined the metallurgical staff of Garringtons, Ltd., Bromsgrove.

▶ Mr. E. J. HANCOCK has been appointed Additional Blast-Furnace Superintendent with Tata Iron and Steel Co., Ltd., India.

▶ Mr. J. W. HAINS has left Cambridge University and is now a graduate trainee in the Aero-Engine Division of Rolls Royce, Ltd.

▶ Mr. A. von HEIJNE, of Stora Kopparbergs Bergslags A.B., Falun, Sweden, is at present with the Ugnstillverkningen, A.B. Svenska Metallverken, Vasteras, Sweden.

▶ Dr. P. HERASYMENKO has taken up an appointment in the Department of Chemical Engineering of New York University, New York, U.S.A.

▶ Dr. O. J. HINETT has taken up an appointment as Assistant Metallurgist with Messrs. Sankey and Sons, Ltd., Hadley Castle Works, Ltd.

▶ Mr. K. B. JOHNSTON has left A.E.C., Ltd., Southall, and is now working at the Test House of the Aeronautical Inspection Directorate, Harefield.

▶ Mr. W. S. LANGFORD has been appointed General Manager of Messrs. F. Issels and Son, Ltd., Bulawayo, Southern Rhodesia.

▶ Dr. R. F. MILLER has left the Carnegie Illinois Steel Corporation to take up an appointment with the United States Steel Company, Pittsburgh, U.S.A.

▶ Dr. E. R. MORGAN has been appointed Research Associate in the Department of Mining and Metallurgy of the University of British Columbia.

▶ Mr. C. W. RIDGE is now with Rhodesian Cables, Ltd., Salisbury, Southern Rhodesia.

▶ Mr. H. G. SARGEANT has left Brown Bayley Steels, Ltd., to take up an appointment as Melting-Shop Manager at Andrews Toledo, Ltd., Sheffield.

▶ Mr. H. C. SHARMA has left Messrs. John Folkes (Lye Forge), Ltd., Worcs., to take up an appointment with Controlled Heat Treatments, Ltd., Coventry.

▶ Mr. W. SOMERVILLE has left Messrs. Stewarts and Lloyds, Ltd., Corby, to take up an appointment with the Wellman Smith Owen Engineering Co., Ltd., London.

▶ Mr. W. A. SMITH has transferred from the Clyde Tube Works of Messrs. Stewarts and Lloyds, Ltd., Coatbridge, to their Department of Research and Technical Development, Corby, Northants.

▶ Mr. P. SPEAR is leaving B.S.A. Tools, Ltd., Birmingham, to take up an appointment with Messrs. Rubery, Owen and Co., Ltd., Darlaston.

▶ Mr. H. WOOLFSON has left the Metallurgical Section of the Control Commission, Germany, to join the board of W. E. Cox and Co. (Steels), Ltd., Sheffield.

▶ Mr. S. C. WORLEY, Managing Director of William King (formerly Edmund Boughton and Co.), Ltd., is at present in the U.S.A. on a business tour of American steel sheet and tinplate stockholders. The tour is linked with the International Foundry Congress.

▶ Mr. U. WYSS has left Messrs. von Roll Ironworks, Gerlafingen, Switzerland, to take up an appointment as metallurgist with Messrs. Maag Gear Wheel and Machine Co., Ltd., Zürich, Switzerland.

Obituary

The Right Hon. Sir ANDREW R. DUNCAN, G.B.E., Chairman of the British Iron and Steel Federation, on 30th March, 1952.

Mr. GRAHAM FORD, of Messrs. H. Oliver Arnold and Co., Ltd., Leeds, in November, 1951.

CONTRIBUTORS TO THE JOURNAL

A. H. Smith, M.Sc.—Department of Metallurgy, University of Manchester. Mr. Smith was born in 1924, and was educated at Manchester Grammar School and at Cheadle Hulme School. After serving with H.M. Forces at sea and later with the British Army in India, he entered Manchester University, where he obtained his B.Sc. degree in 1950 and his M.Sc. degree in 1951.

F. Hargreaves, A.R.S.M., D.I.C., F.R.I.C., F.I.M.—Regional Works Metallurgist, Southern Region, British Railways. Mr. Hargreaves studied at the Royal School of Mines, Imperial College, from 1908 to 1912, when he was awarded the Associateship. After spending two years at the reduction plant of Simmer and Jack Mines, Transvaal, he was appointed Assistant in the Department of Metallurgical Chemistry, University of Glasgow. He joined Nobel's Explosive Co., Ardeer, as Chemist in 1915. In 1919 he was appointed Chemist with the Southern Railway, Ashford, and subsequently transferred to Eastleigh as Chemist and Metallurgist in 1933.

Mr. Hargreaves was elected an Associate of the Royal Institute of Chemistry in 1918 and a Fellow in 1923. He was elected a Fellow of the Institution of Metallurgists in 1948. He has read several papers before the Institute of Metals, on work-softening of metals and alloys. He has also published papers on welding and stereo-radiography. He took up his present appointment in 1951.

R. E. Lismer, F.I.M.—Head of the Metallographic Section of the Research and Development Department of The United Steel Companies, Ltd., Rotherham. Mr. Lismer was educated at Nether Edge Grammar School, Sheffield, and studied at Sheffield University, where he was awarded the Associateship in Ferrous Metallurgy in 1937. He joined The United Steel Companies, Ltd., in 1933, and has been in charge of the Metallographic Section since 1940.

Mr. Lismer was elected an Associate of the Institution of Metallurgists in 1946 and a Fellow in 1952. He is a member of the Solid Steel Study Group of the Gases and Non-Metallics Sub-Committee of the British Iron and Steel Research Association.

L. Pryce, A.I.M.—A member of the staff of the Metallographic section of the Research and Development Department of The United Steel Companies, Ltd., Rotherham. Mr. Pryce was born in 1915, and was educated at Rotherham Grammar School. He was awarded the Associateship in Ferrous Metallurgy of Sheffield University in 1939, and was elected an Associate of the Institution of Metallurgists in 1946. From 1935 to 1942 he was employed as a Research Metallurgist with Hall and Pickles, Ltd., Sheffield. He was appointed Assistant Chief Metallurgist at Guest, Keen and Nettlefolds, Ltd., Smethwick, in 1942, and in 1943 he joined Exors. of James Mills Ltd., Woodley, as Research Metallurgist. He took up his present appointment in 1948.

K. W. Andrews, D.Phil., B.Sc., A.Inst.P., F.I.M.—In charge of the X-ray Crystallography Section of the Research and Development Department, The United Steel Companies, Ltd., Rotherham. Dr. Andrews was born at Spalding, Lincolnshire, and was educated at Boston Grammar School. He entered Manchester University in 1935 and graduated with 1st class honours in metallurgy in 1938. From then until 1942 he carried out research on the structure and constitution of alloys, at Oxford University, where he received the degree of D.Phil. in 1940. He joined The United Steel Companies, Ltd., in 1942, and has been mainly concerned with applications of X-ray crystallography; he has held his present position since 1947.

W. E. Dennis, B.Sc.(Hons.)—Member of the Nuffield Research Group in Extraction Metallurgy at Imperial College, London. Mr. Dennis was born in 1926 and was educated at Barnard Castle School and at King's College, University of Durham, where he graduated with 2nd Class Honours in Metallurgy. In 1951 he was awarded an E.C.A. scholarship and spent one year at the Carnegie Institute of Technology in the U.S.A., where he carried out research on the electrochemistry of molten slags. In 1952 he returned to London and joined the Nuffield Research Group, where he is now investigating the thermodynamics of liquid iron–carbon–chromium alloys, under Dr. F. D. Richardson, on a B.I.S.R.A. research grant.

H. Flood, Dr. Ing.—Lecturer in Inorganic Chemistry at the Technical University of Norway, in Trondheim, Dr. Flood was born in 1905, and was educated at the Technical University. He was awarded a doctorate of the Technische Hochschule, Berlin, in 1933. He is Head of Norges Teknisk Naturvitenskapelige Forskningråds.

A. H. Smith

R. E. Lismer

L. Pryce

K. W. Andrews

W. E. Dennis

H. Flood

K. Grjotheim

Institutt for Silikatforskning (Institute of Silicate Science).

K. Grjotheim—Institute of Silicate Science, Trondheim. Mr. Grjotheim was born in 1919, and was educated at the Technical University of Norway, in Trondheim. He worked for one year as Assistant at the Institute of Silicate Science, and has been awarded a Fellowship from the Royal Norwegian Council for Scientific and Industrial Research.

IRON AND STEEL ENGINEERS GROUP

A Meeting of Junior Engineers (under the age of 35) will be held at Ashorne Hill, Leamington Spa, from Monday to Wednesday, 19th–21st May, 1952. The programme was given in the News Section of the April issue of the *Journal*.

The **Nineteenth Meeting** of the Group will be held on **Wednesday, 15th October, 1952,** when there will be a discussion on Continuous Hot Mills.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Cathodic Protection Against Corrosion of Buried Metals

The application of cathodic methods of protection will only be effective if the fullest possible information on the subject is examined, correlated, and made available to all interested bodies. The B.I.S.R.A. Sub-Committee on the Corrosion of Buried Metals has been entrusted by the Minister of Health with the co-ordination of research on this subject. A standard form for describing cathodic protection installations to safeguard underground pipelines in this country against corrosion has been prepared by the Sub-Committee. These forms are available from Mr. E. E. White, British Iron and Steel Research Association, 140, Battersea Park Road, London, S.W.11, and should be returned when completed to the Chemical Research Laboratory of the D.S.I.R., Teddington.

NEWS OF SCIENCE AND INDUSTRY

Mond Nickel Fellowships

The Mond Nickel Fellowships Committee invites applications for the award of Mond Nickel Fellowships for the year 1952. Awards will be made to selected applicants of British nationality, educated to University degree or similar standard, although not necessarily qualified in metallurgy, who wish to undergo a programme of training in industrial establishments: they will normally take the form of travelling Fellowships—awards for training at Universities may be made in special circumstances. There are no age limits although awards will seldom be given to persons over 35 years of age. Each Fellowship will occupy one full working year. The Committee hope to award up to five Fellowships each year, of an average value of £750 each.

Mond Nickel Fellowships will be awarded in furtherance of the following objects:

(*a*) To allow selected persons to pursue such training as will make them better capable of applying the results of research to the problems and processes of the British metallurgical and metal-using industries.

(*b*) To increase the number of persons who, if they are subsequently employed in executive and administrative positions in the British metallurgical and metal-using industries, will be competent to appreciate the technological significance of research and its results.

(*c*) To assist persons with qualifications in metallurgy to obtain additional training helpful in enabling them ultimately to assume executive and administrative positions in British metallurgical and metal-using industries.

(*d*) To provide training facilities whereby persons qualified in Sciences other than Metallurgy may be attracted into the metallurgical field and may help to alleviate the shortage of qualified metallurgists available to industry.

Applicants will be required to state the programme of training in respect of which they are applying for an award, as well as particulars of their education, qualifications, and previous career. Full particulars and forms of application can be obtained from the Secretary, Mond Nickel Fellowships Committee, 4 Grosvenor Gardens, London, S.W.1.

Completed application forms will be required to reach the Secretary of the Committee not later than 1st June 1952.

Institute of British Foundrymen

The Forty-ninth Annual Conference will be held at Buxton, Derbyshire, from 10th to 13th June, inclusive. This conference is organized by the Sheffield and District Branch of the Institute, and Dr. C. J. Dadswell, a Past-President of that branch, will be installed in the office of President of the Institute during the Conference. Further details may be obtained from the offices of the Institute, St. John Street Chambers, Deansgate, Manchester, 3.

International Congress on Analytical Chemistry

An International Congress on Analytical Chemistry will be held at the Examination Schools, Oxford, under the patronage of the International Union of Pure and Applied Chemistry from 4th–9th September, 1952. President of the Congress is Sir Robert Robinson, O.M., D.Sc., F.R.S. The Vice-President is Sir Wallace Akers, C.B.E., F.R.I.C.

Three main Congress lectures will be given by Professor C. J. van Nieuwenburg, Professor of Chemistry, Technical College of Delft, Holland, Dr. Ralph H. Müller, Los

Alamos Scientific Laboratory, New Mexico, and Dr. L. H. Lampitt, Chief Chemist and Director, J. Lyons & Co., Ltd., England. The scientific sessions will be divided into nine sections : microchemical, biological, electrical, optical, radiochemical, organic complexes, reporting of results, adsorption and partition methods, and miscellaneous techniques. The whole of the proceedings will be published, as soon as possible after the Congress, in a special number or numbers of *The Analyst*.

During the Congress there will be working demonstrations, illustrating new techniques or special applications of older techniques in analytical chemistry. There will also be a trade exhibition comprising apparatus and books. Social functions and excursions to places of interest have been planned, and a special programme will be arranged for ladies not taking part in the scientific sessions.

Further details may be obtained from the Honorary Secretary of the Congress, Mr. R. C. Chirnside, Research Laboratories, The General Electric Co., Ltd., Wembley, Middlesex.

Fifth Empire Mining and Metallurgical Congress

As already announced in the March issue of the *Journal*, the Fifth Congress is being held in Australia and New Zealand during April and May, 1953. Messrs. Thos. Cook and Son, Berkeley Street, London, W.1, have been appointed official travel agents for the Congress, and they invite Members who may be taking part to communicate with them regarding travel arrangements.

Industrial Publications

▶ A publication issued by Henry Wiggin and Co., Ltd., gives all the available information on the Nimonic series of alloys. Tables of their physical and mechanical properties are given, together with a series of graphs giving design data of these nickel–chromium alloys at various temperatures. The heat-treatment and acceptance creep tests laid down in the appropriate D.T.D. Specifications are included. A list of typical applications shows that these nickel–chromium alloys, in addition to their use as the standard material for turbine blades in British aircraft gas turbines, have a wide field of application for many other components which operate at elevated temperatures.

▶ Some of the many different ways in which Tufnol has been successfully used to overcome problems of design, production, and maintenance in various industries, are described in a 30-page booklet entitled " Uses for Tufnol."

▶ The ' Deoxo ' process has been developed for the catalytic removal of oxygen from industrial gases, such as hydrogen and nitrogen, which are used in certain metallurgical operations such as bright annealing and the manufacture of powder metals. In the process, developed by Baker and Co., Inc., and recently demonstrated at an Institute of Metals conversazione, the oxygen combines with hydrogen in the presence of a specially prepared catalyst, to form water vapour, which is removed by a dehydrator. ' Deoxo ' units with capacities of 5, 200, 1000, 2500, and 5000 cu. ft./hr. are available.

Units are also being developed to provide for the catalytic combinations of :

(*a*) Oxygen and hydrogen in the presence of carbon monoxide
(*b*) Oxygen and carbon monoxide to form carbon dioxide in gases that do not contain hydrogen
(*c*) Carbon monoxide in hydrogen to form carbon dioxide
(*d*) Carbon monoxide and hydrogen to form methane and water vapour.

DIARY

1st May—LEEDS METALLURGICAL SOCIETY—Annual General Meeting and Junior Members' Papers—Chemistry Department, The University, Leeds 2, 7 P.M.

3rd May—INSTITUTION OF CHEMICAL ENGINEERS (Midlands Branch)—" Stainless Steel in Chemical Plant," by A. M. Hucheson—Latin Theatre, The University, Edmund Street, Birmingham, 3 P.M.

14th May—SOCIETY OF CHEMICAL INDUSTRY—Annual General Meeting—Papers on " *The Prevention of Corrosion in Packaging*," by the Corrosion Group, Corrosion Research Laboratories, Teddington, 6.15 P.M.

14th May — PURCHASING OFFICERS' ASSOCIATION — Annual Meeting—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 7.30 P.M.

18th–25th May—DECHEMA (Deutsche Gesellschaft für Chemisches Apparatewesen E.V.)—(Joint Meeting with Société de Chimie Industrielle, Paris)—Frankfurt-on-Main.

19th–21st May—IRON AND STEEL ENGINEERS GROUP—Meeting of Junior Engineers—Ashorne Hill, Leamington Spa.

20th May—BRITISH COKE RESEARCH ASSOCIATION—Fifth Conference—" Further Studies of Coking Pressure "—William Beveridge Hall, University of London, Malet Street, W.C.1, 2.30 P.M.

29th May—INCORPORATED PLANT ENGINEERS—"Foundry Mechanization," by P. McA. Martin—Grand Hotel, Sheffield, 7.30 P.M.

TRANSLATION SERVICE

(The previous announcement was made in the April, 1952, issue of the *Journal*, p. 378).

TRANSLATIONS AVAILABLE

No. 439 (Polish). K. RADZWICKI, W. MADEJ, and W. STRONCZAK : " Briquetting of Ore Fines for Steel Plants." (*Prace Głównego Instytutu Metalurgii*, 1951, No. 3, pp. 173–181.)

No. 440 (German). E. AMMANN and J. HINNÜBER : " The Development of Cemented Carbide Alloys in Germany." (*Stahl und Eisen*, 1951, vol. 71, Oct. 11, pp. 1081–1090.)

No. 441 (Russian). K. A. OSIPOV : " On the Mechanism of Plasticity in Homogeneous Metal Alloys at High Temperatures." (*Izvestiya Akademii Nauk SSSR, Otdelenie Tekhnicheskikh Nauk*, 1949, No. 9, pp. 1372–1377.) (Translation made available through the courtesy of the National Physical Laboratory, Teddington, Middlesex.)

TRANSLATIONS IN COURSE OF PREPARATION

(German). E. MARTIN : " Ultrasonic Testing of the Axles of Railway Rolling Stock." (*Stahl und Eisen*, 1952, vol. 72, Feb. 14, pp. 176–185.)

(German). K. HEINRICH : " The Use of Oxygen in Basic Open-Hearth Furnace Operation." (*Stahl und Eisen*, 1951, vol. 71, Nov. 8, pp. 1199–1204.)

(German). G. TRÖMEL and W. OELSEN : " Calcium Phosphate Melting Crucibles. On the Metallurgy of the Basic Bessemer Process." (*Archiv für das Eisenhüttenwesen*, 1952, vol. 23, Jan.–Feb., pp. 17–20.)

CHARGES FOR COPIES OF TRANSLATIONS—The charge for translations is £1 for the first copy and 10*s.* for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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ORES—MINING AND TREATMENT

Fosdalens Bergverks-Aktieselskab. T. Amdahl. (*Tidsskr. Kjemi, Bergvesen Met.*, 1950, **10,** Mar., 61–65). [In Norwegian]. The Norwegian state mine of Fosdalen is described. The production capacity is 250,000 tons of iron-ore concentrates and 10,000 tons of pyrites concentrates yearly.—B. S. E.

A/S Rödsand Gruber. O. Överlie. (*Tidsskr. Kjemi, Bergvesen Met.*, 1950, **10,** Mar., 111–112). [In Norwegian]. The Rödsand mines are briefly described. Production capacity is 45,000 tons of magnetite concentrate per annum.—B. S. E.

Aktieselskabet Sydvaranger. J. K. Johanssen. (*Tidsskr. Kjemi, Bergvesen Met.*, 1950, **10,** Mar., 134–143). [In Norwegian]. The restoration of the Sydvaranger mines after the war has been described. Geology, mining, and dressing are surveyed. By 1952, 800 men will be employed and 1,000,000 tons/annum of dressed ore, briquettes, and pellets will be produced.—B. S. E.

Rana Gruber A.s. W. Lund. (*Tidsskr. Kjemi, Bergvesen Met.*, 1950, **10,** Mar., 106–110). [In Norwegian]. The Rana magnetite and hematite are estimated to be capable of supplying 1,000,000 tons/annum of ore for the next 50 years.—B. S. E.

A.s Knaben Molybdaengruber. A. Christensen. (*Tidsskr. Kjemi, Bergvesen Met.*, 1950, **10,** Mar., 83–87). [In Norwegian]. Works organization at the mine and ore-dressing plant at Knaben are described.—B. S. E.

Comparative Laboratory Tests with Jaw Crushers. S. Mörtsell. (*Jernkontorets Ann.*, 1951, **135,** 9, 529–552). [In Swedish]. Crushers of the Dodge and Blake type have been used for the comminution of a series of different materials. An attempt is made to correlate ore characteristics with crushing capacity.—B. S. E.

The Cyclone as a Separator Tool in Mineral Dressing. K. A. Fern. (Inst. Chem. Eng.: *Mining J.*, 1952, 238, Feb. 15, 168–170). The author discusses cyclones using heavy suspensions for mineral separation and reports cyclone tests on tin, lead, and pyrite ores, and red iron ore.—R. A. R.

FUEL—PREPARATION, PROPERTIES, AND USES

International Flame-Radiation Trials in Holland. (*Engineering*, 1951, **172,** Dec. 7, 705–706). A review is given of the work carried out in the past two years on flame radiation on experimental furnace at the Royal Netherlands Steel Company at Ijmuiden.—M. D. J. B.

Investigation of Flame Radiation: Results of an International Research Group Using an Experimental Furnace at Ijmuiden, Holland. G. M. Ribaud, J. E. de Graaf, O. A. Saunders, and M. W. Thring. (*Iron Coal Trades Rev.*, 1951, **163,** Nov. 30, 1181–1186). The authors present the results obtained in trials at the Royal Netherlands Iron and Steel Works, Ijmuiden, to elucidate the mechanism of luminous radiation and its heat transfer. The type of fuel and type of atomizing agent used affect radiation and other conditions of the early part of the flame, whilst the quantities of fuel, atomizing agent, and combustion air affect flame radiation, temperature, and emissivity in the tail of the flame. The results are of immediate practical value to designers concerned with similar types of flame to those used in the trials.—G. F.

International Committee of Studies on Flame Radiation: Results and Conclusions of Works Trials Carried Out at Ijmuiden During the Year 1949. J. E. de Graaf and M. W. Thring. (*Chaleur et Ind.*, 1951, **32,** July, 175–184). The effects of five variables on flame radiation were studied. They were the type of combustible (fuel oil and tar creosote), quantity of combustible, air and steam as atomizing agents, quantity of atomizing agent, and quantity of air for combustion. The results are discussed, and various conclusions of practical importance concerning flame radiation in furnaces are drawn.—T. E. D.

Fuel Economy in a Steel Plant. S. N. Sircar. (*Tisco Rev.*, 1951, **19,** Oct. 491–493, 528–532). The fundamentals of fuel economy are reviewed. The major units using fuel in a steelworks are considered specifically from the point of view of reducing costs; they include locomotives, boilers, coke ovens, blast-furnaces, steel-melting furnaces, soaking pits, reheating furnaces, and annealing and normalizing furnaces.—T. E. D.

Experiments on Economic Burning of Producer Gas in Burners for Flameless Combustion. F. I. Shklayev. (*Za Ekonomiyu Topliva*, 1947, No. 4: *Hutnické Listy*, 1951, **6,** No. 5, 255–258). [In Czech]. Russian experiments with the application of burners for flameless combustion are described. The injector-type burners are preferred and it is claimed that during the war (1939–45) a saving of 15 million cu. m. of producer gas per annum was obtained by introducing burners for catalytic combustion. Formulæ are presented for calculating the dimensions of injector burners for fuels of different calorific value.—E. G.

Using Electric Furnaces and Heaters to Determine the Free Swelling Index of Coal. E. Swartzman and G. C. Behnke. (*Min. Eng.*, 1951, **3,** Oct., 871–878). A method employing an electric cone heater and standard platinum crucibles is suggested.—E. C.

Installation of a Coal-Preparation Plant: Details of a New Project. J. G. Gray. (*Iron Coal Trades Rev.*, 1951, **163,** Dec. 14, 1303–1306). The author discusses the hypothetical installation of a new coal-preparation plant, and indicates the

procedure adopted from the time that decisions are taken to instal a new plant until it is in operation. This includes the drawing up of a contract, construction, and final tests.—G. F.

Ball Coke from Long Year Coal. L. A. Conradi. (*Tekn. Ukeblad*, 1951, **98**, Apr. 5, 253–261 ; Apr. 12, 278–283). [In Norwegian]. Coals from the King's Bay mine, Spitzbergen, were found to be suitable for low-temperature carbonization by the Disco rotary retort method. The coke obtained was fit for metallurgical uses, since it was very reactive and could be agglomerated with up to 60% iron ore concentrates incorporated. The agglomerates compared favourably with sinters for smelting in electric furnaces, requiring 30% less energy. These agglomerates were also an ideal burden for low-shaft furnaces of the cupola type. The Ore-Disco system was proved successful even in non-ferrous metallurgy. As a by-product a comparatively high yield of tar rich in phenolic compounds was obtained. A development scheme based on Spitzbergen coal could make the Norwegian industry independent of imported metallurgical coke and tar products.—B. S. E.

Low Temperature Coke by the Disco Process. C. E. Lesher. (*Tidsskr. Kjemi, Bergvesen Met.*, 1951, **11**, Oct., 115–119). [In English]. The 'distilled coal' process for carbonizing small-sized bituminous fuels is described. Mention is made of the Ore-Disco agglomeration, where up to 60% iron ore fines is incorporated.—B. S. E.

TEMPERATURE MEASUREMENT AND CONTROL

A Photographic Pyrometer. D. W. Male. (*Rev. Sci. Instruments*, 1951, **22**, Oct., 769–772). The instrument described indicates apparent surface temperatures by photographing hot surfaces and correlating the variable density of the photographic negative with the apparent surface temperature. The need for critically controlled photographic and development techniques is eliminated by incorporating into every photograph the images of standard targets.—B. G. B.

Standard Definitions for Thermometers. F. Lienoweg. (*BWK*, 1951, **3**, Nov., 381–383). Terms and definitions used in the German Standards (DIN) relating to industrial temperature-measuring instruments of all kinds are presented and discussed.

REFRACTORY MATERIALS

Ceramic and Refractory Clays of South Australia. A. J. Gaskin and H. R. Samson. (*Dept. of Mines Geol. Survey S. Australia*, 1951, *Bull. No.* 28).

Through New Developments in Metallurgical Refractories. W. F. Rochow and J. S. McDowell. (*J. Met.*, 1951, **3**, Oct., 846–853). The authors discuss recent developments in metallurgical refractories with particular reference to the refractories used in copper-smelting furnaces.—G. F.

Experimental Automatic Operation of a Tunnel Kiln for Firing Firebricks. A. E. Myerlin and B. K. Dolgis. (*Ognyeupory*, 1951, 1, 9–22 : *Hutnické Listy*, 1951, **6**, June, 309). A tunnel kiln 148·5 m. long, 2·2 m. wide, and 1·495 m. high, fired by cold producer gas mixed with air preheated in the cooling of the finished bricks is described.—E. G.

A Protective Coating for Refractories. (*Gas Times*, 1951, **69**, Nov., 260). The application of glazed coatings known as Brickseal is described. Details of the five coatings available are given. These mixtures of fine-grain refractory clays and metallic oxides fuse at the vitrification temperature to a soft glaze which is sufficiently plastic to expand and contract with the furnace wall and withstand considerable abrasion, even when hot. The maximum recommended operating temperatures vary between 1100° and 1540° C. for different coatings. A special coating is available which sets at atmospheric temperature and becomes progressively harder up to 1980° C.

Analysis of Errors in Measuring Thermal Conductivity of Insulating Materials. E. V. Somers and J. A. Cyphers. (*Rev. Sci. Instruments*, 1951, **22**, Aug., 583–586). Thermal conductivity measurements made by the guarded hot-plate method are subject to error from heat loss by convection at the exposed edge of the sample. Analytical solutions are plotted to show the maximum errors for square and round samples in apparatus of various dimensions.—B. G. G.

A Rapid Calculator of Apparent Porosity, Bulk Density, and Apparent Solid Density. J. R. Lakin. (*Trans. Brit. Cer. Soc.*, 1951, **50**, May, 208–214). A circulator chart is described with which direct readings of bulk density and apparent solid density can be obtained from the three weighings made in the standard method for determining apparent porosity, bulk density, and apparent solid density—weight dry W_A, weight suspended W_B, and weight soaked W_C. Having obtained the bulk density and apparent solid density, the apparent porosity can then be read directly from another similar chart.—E. J. D. S.

The Fabrication of Pure Calcium Oxide and a Study of Its Hydration. A. E. Williams. (*Trans. Brit. Cer. Soc.*, 1951, **50**, May, 215–224). Pure lime can be fabricated into crucibles and other articles, the product having a bulk density of about 2·8 g./c.c. Precautions to prevent hydration in the green and fired states are given.—R. A. R.

Methods of Testing Refractory Products. L. Halm. (*Etudes Document. Mét.*, 1951, July–Aug.–Sept., Bull., 83–112). A general discussion on testing methods for refractory materials is presented. 'Pyroscopic resistance' is defined, and examples of classification of silico-aluminous and fireclay refractories are given. Seger and Orton scales are compared. Plastic deformation, mechanical resistance, and resistance to thermal shock are mentioned. The measurement of porosity, permeability, and thermal conductivity is discussed, and the study of structure by X-rays and microscope is outlined. (22 references).—T. E. D.

Testing Steel Plant Refractories at Abbey Works : Suitability Assessed for Large-Scale Use at the Steel Company of Wales, Limited. (*Iron Coal Trades Rev.*, 1951, **163**, Nov. 23, 1133–1135 : *Refract. J.*, 1951, **27**, Nov., 459–463). This article describes the exhaustive testing and choice of refractories for various applications at the Abbey Works of the Steel Company of Wales, Limited. The scope of the tests applied is briefly reviewed with examples.—G. F.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Features of the Planning of an Electric Smelting Plant for Pig Iron at Mo i Rana. B. M. Müller. (*Tidsskr. Kjemi, Bergvesen Met.*, 1949, 9, May, 74–79). [In English]. The author gives the layout of an electric pig-iron smelting plant to produce 60,000 tons/annum.—B. S. E.

Norsk Jernverk. U. Styren. (*Tekn. Ukeblad*, 1951, **98**, May 10, 351–357 ; May 17, 373–382). [In Norwegian]. The historical background of the state development scheme of 1946 for the development of the Mo i Rana works now under erection is given. The adjacent Dunderland ore field is estimated to yield 2,000,000 tons of ore (about 33% Fe) per annum. A concentration process for the magnetite-hematite ore has been developed. The ironworks will initially produce 180,000 tons of iron in three Tysland-Hole electric furnaces of 20,000 kW. each. The burden will at first consist of sinter and pellets from Sydvaranger and Fosdalen concentrates.—B. S. E.

On the Possibilities of Combining Production of Rich Gas and Iron. H. Koppenberg and W. Wenzel. (*BWK*, 1951, **3**, July, 217–219). Gas of high calorific value and iron may be produced simultaneously in a low-shaft furnace operated on concentrated oxygen. The process is shown to be economically acceptable. Its advantages include utilization of low-grade ores and fuel, and independence from coke supplies and prices.—E. C.

The Operation of Hot Blast Stoves with Waste Gas Circulation. A. Rein and O. J. Stebel. (*Stahl u. Eisen*, 1951, **71**, Nov. 22, 1310–1313). The operational data are reported from a group of stoves whose hood temperatures were held at a prescribed value over a period of 14 weeks by the addition of excess air. Comparison with a 24-week period, in which excess air was replaced by stove waste gas, showed the advantage of the waste-gas circulation procedure. This advantage is a 3–10% saving of hot gas, depending on the air excess and the initial waste-gas temperature, protection of the most highly stressed brickwork, and security against the effects of operational error. After putting the waste-gas circulation plant into operation, there was an unexpected increase in the efficiency of the stoves. The plant cost was soon repaid by the saving in gas ; in fact, the monthly amortization together with the operating cost of the whole circulating plant, amounted to less than 10% of the possible gas saving.—J. P.

Plant Extensions at Port Kembla Steelworks. (*Chem. Eng. Min. Rev.*, 1951, **44**, Oct., 3–5). Details are given of the construction of No. 3 Blast Furnace, Port Kembla, Australia. The hearth is 26 ft. 6 in. in dia. and the working volume is

40,590 cu. ft.; there are 16 tuyeres. Interlocking electrical controls are fitted to the filling system to charge coke automatically from weighing hoppers. A Brown-Boveri turboblower driven by a 12 060-h.p. steam turbine with a capacity of 100,000 cu. ft./min. of air at 30 lb./sq. in. will be installed.

Review of Methods of Increasing Blast Furnace Production. J. M. Stapleton. (*Amer. Iron Steel Inst. Regional Meeting*, 1951). This paper briefly describes methods that have been or may be employed to improve blast-furnace production. Raw materials and possible improvements in the design and operation of the furnace and its auxilary equipment are considered; finally the factors affecting furnace life, and in particular the quality of the refractories, are discussed.—G. F.

The Blast-Furnace Process is Modernized. S. Hähnel. (*Tekn. Tidskr.*, 1951, **81,** Oct. 13, 825–834). [In Swedish]. Swedish blast-furnace research and development in the past 35 years has resulted in many improvements, notably the sponge-iron process. High top pressure, oxygen-enriched blast, and ore beneficiation are assessed as economy and capacity factors. Low-shaft furnaces as used in Germany and Switzerland are mentioned.—B. S. E.

The Low-Shaft Blast Furnace International Project. T. E. Dancy. (*Coke Gas*, 1952, **14,** Jan., 22). The constitution of the directing committee is given, together with details of the design of plant to be used. The proposed trials at S.A Ougrée-Marihaye, Liège, Belgium, will include the smelting of fine Minette ore with fine coke; later trials will use high top pressure and oxygenated blast.—T. E. D.

PRODUCTION OF STEEL

The Use of Oxygen in the Basic Open-Hearth Furnace. K. Heinrich. (*Stahl u. Eisen*, 1951, **71,** Nov. 8, 1199–1204). The oxygen enrichment of the combustion air in a gas producer to 23·5% increases the calorific value of the producer gas from 1400 to about 1530 kg.cal./cu. m. This improved fuel reduces the heat consumption of the open-hearth furnace and increases output. The heat consumption can be further reduced by addition of oxygen in the furnace and this gives an extra increase in the hourly output rate. Considerable advantages result from the use of the oxygen lance for refining, though this leads to decreased furnace life. In spite of this, however, the total output from a particular furnace was 15·5% higher than without adding oxygen. Steel can be produced for DM 1.80 per ton less than when using air only.—J. P.

The Use of Oxygen-Enriched Combustion Air in the Open-Hearth Furnace and the Gas Producer. W. Baumgardt. (*Stahl u. Eisen*, 1951, **71,** Nov. 8, 1204–1211). Trials using oxygen-enriched air for combustion showed that it is possible in this way to bring up more quickly the temperatures of the roof and checkers after charging; a furnace fed with enriched air was back to maximum temperature in 2¼ hr. as against the usual 5–5½ hr. As a result of the more rapid combustion, the zone of maximum temperature is displaced from the centre towards the inlet port end. The flame is shortened, and its temperature rises from around 1700° to 1800° C. The trials were carried out using normal and then increased fuel rates. Best results with respect to melting efficiency and fuel consumption per ton were obtained in the latter instances, since it was then possible to introduce more gas and without increasing the volume of waste gas, because of the decreased quantity of nitrogen. An enrichment to 26–27% oxygen proved to be the most practicable. Hourly output increased by 19% and the fuel per ton decreased by 13%, in spite of the increased hourly heat consumption. The results showed that, given an efficient oxygen plant and increased attention to furnace maintenance, this process can be carried out without endangering the furnace and offers real advantages. Enrichment of the gas-producer blast to 25% oxygen is practicable with a revolving grate producer and leads to improved gas.—J. P.

Oxidation Period in Oxygen Injection in Melting Acid Electric Steel. R. H. Jacoby, M. Petty, and J. Mitchell. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8,** 135–139). Oxygen injection practice in acid electric furnaces at the Key Company, East St. Louis, is described, and the rules adopted are outlined. After injection, the bath is held for at least 15 min. to allow the action to subside, as this practice reduces porosity in the castings.—G. F.

Oxygen Practice at Oklahoma Steel Castings Company. J. H. Garrison. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8,** 140–148; *J. Met.*, 1951, **3,** Aug., 601–602). The author describes the oxygen injection practice employed in 2-ton acid electric furnaces at Oklahoma Steel Castings Co., Tulsa. Average steel and slag analyses before and after oxygen injection are given, and average data obtained from oxygen practice are compared with those from ore practice.—G. F.

A New Departure in Steel Production. L. F. Reinartz. (*Amer. Iron Steel Inst. Regional Meeting*, 1951). A detailed account, with 22 illustrations, is given of the rapid scrap-charging system at the new open-hearth shop of the Armco Steel Co., Middletown, which incorporates a hydraulic hoist with a capacity of 83,400 lb. and a lift of 20 ft. 6 in. which raises the scrap car from the basement to the charging platform. (*See J. Iron Steel Inst.*, 1952, **170,** Jan., 67).

The Soderberg Electrodes and their Influence on Furnace Design. M. Ö. Sem. (*Tekn. Ukeblad*, 1951, **98,** Dec. 13, 923–930; Dec. 20, 953–959). [In Norwegian]. The development of the Söderberg electrode has proceeded along lines anticipated by the inventor 30 years ago, and has facilitated electric smelting in increasingly large furnaces, usually with triangular electrode arrangement. The economic and hygienic importance of closed and semi-closed furnaces for smelting and calcium carbide production is stressed. Recently, improved pneumatic electrode holders and electrode casing reinforcement have been devised in Scandinavia. The average electrode costs are 50% less than those for graphite electrodes used in the U.S.A. The problems of electrodes with a central hole for charging and degassing are not yet satisfactorily solved.—B. S. E.

Quality Control in Basic Electric Steel Making Practice. A. F. J. Edgerton. (Australian Inst. Metals: *Australasian Eng.*, 1951, Oct. 8, 74–81). The basic principles of electric steelmaking are described, and the practice at the Brooklyn works of the Melbourne Iron and Steel Mills Pty. Ltd. is outlined. The author also discusses the effects of some of the alloying elements added to the liquid steel, in the light of the specification requirements.—P. M. C.

Use of Iron Ore in Steelmaking. J. E. Arthur. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8,** 5–7). The author discusses iron ore as a source of oxygen in basic electric furnace steelmaking practice. The existing American deposits of suitable charge ores are reviewed, and the importance of taking the impurities into account is emphasized.—G. F.

Top Charging and High Voltages in Lining Life and Repair. R. J. McCurdy. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8,** 70–71). The author briefly describes the construction and operation of a top-charged 70-ton basic electric furnace at the Republic Steel Corp., Chicago, and discusses factors affecting the life of the roof and lining. These include the voltage and amperage employed, exposure of the roof to cold air, and electrode alignment.

Relining Electric Furnaces. C. F. Staley. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8,** 76–77). A brief description is given of the procedure used at the Armco Steel Co., Middletown, Ohio, for relining electric furnaces, one feature being the use of a water-cooled working platform set inside the furnace. The total time for relining a 100-ton furnace, from tap to power on, averages 14½ hr.—G. F.

Application of Resistance Indicator to Electric-Arc Furnaces. A. Sherman. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8,** 80–90). In electric furnace practice, the full utilization of power and corresponding savings on production costs are possible only if the electrical contacts are maintained in the best possible condition. The author illustrates the detrimental effects of bad contacts, and describes a resistance indicator which can be applied to electric furnaces to decrease delays, lower production costs, and increase efficiency.—G. F.

Some Observations on the Metallurgy of Electric-Furnace Melting. C. R. Taylor. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8,** 91–97). The author discusses the rôle of the metallurgist in electric furnace melting practice, and the problems of meeting analysis specifications, sulphur control, the effects of sulphur and nitrogen on the properties of the steel, and the control of inclusions.—G. F.

Practical Aspects of Tool-Steel Melting. C. F. Sawyer, jun. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8,** 98–103). The practical aspects and differences in the techniques employed in the melting of different tool steels

in the basic electric-arc furnace are discussed. Furnace construction, the charging and melting procedures for low and high carbon and highly alloyed tool steels are described.

Rimmed and Semikilled Steels. P. Lindberg. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8**, 112–115). After outlining the general layout and facilities of the electric furnace melting department of the McLouth Steel Corp. at Trenton, Michigan, the author describes the production of semi-killed and rimming steels.—G. F.

Recent Trends in Stainless Melting Practice. A. C. Ogan. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8**, 120–124). The author discusses recent trends in electric furnace practice when making stainless steels. Particular mention is made of induction stirring practice, improved slag control, the use of Mischmetal to improve cleanliness and rollability, bath temperature control, and the Kellogg electric hot-topping equipment.—G. F.

Ore Practice in an Acid Electric Furnace. F. J. Stanley. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8**, 125–129 : *J. Met.*, 1951, **3**, Aug., 603–604). Typical data from 17 heats from a 12-ton acid electric furnace at the McConway and Torley Corporation, Pittsburgh, are presented. The practice includes the addition of part of the ore with the charge, resulting in a decrease of overall heat time.—G. F.

Ore Practice in Making Acid Electric Steel. W. L. Doyle. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8**, 130–134). The ore practice used in making acid electric furnace steel at the Pittsburgh Steel Foundry Corp., McKeesport, is described, and details from five heats of slag and metal analyses at melt, after the boil, and before ferro-alloy addition, are given. The amount of pig iron required for recarburization is estimated from the intensity of the boil.

Effect of Various Types of Final Deoxidizers on Physical Properties of Class B Cast Steel. C. Wyman. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8**, 159–173). Investigations were made to determine the effectiveness of various deoxidants in the final deoxidation practice in acid electric furnace steelmaking. The effects of various additions on the physical properties, sulphur content, and inclusions content are summarized. In all cases, the strength properties of bars containing aluminium are greater than those of bars containing no aluminium.—G. F.

Steels Deoxidized with Silicon. J. A. Bowers. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8**, 174–180). The author describes tests on the effect of silicon on the occurrence of pinhole porosity in induction and arc furnace steels containing no aluminium. Freedom from porosity occurs only within a certain range of silicon content, the upper and lower limits of which increase as the carbon content increases. Pinhole formation tends to increase as the teeming temperature increases.—G. F.

Rating Inclusion Structures in Cast Steels and Their Effects on Tensile Properties. E. A. Loria. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8**, 191–209). The author describes studies of such deoxidizers as calcium–silicon, silicon carbide, and calcium–manganese–silicon, to determine their effect on the nature and distribution of inclusions in electric furnace steel and the resultant tensile properties. The addition of complex silicon alloys does not produce embrittling sulphide inclusions, and variation in size and quantity of round or angular inclusions has little effect on ductility.—G. F.

Residuals. J. S. Marsh. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8**, 245–250). The author discusses residual elements in electric furnace steel, dealing with those elements which either distribute themselves between the slag and metal or are absorbed almost entirely by the metal. Methods of removing the elements are considered.—G. F.

Progress in Electric Steelmaking. C. F. Hood. (*Amer. Inst. Min. Met. Eng., Proc. Elec. Furn. Steel Conf.*, 1950, **8**, 253–260). Progress in the field of electric steelmaking is reviewed, and special problems are considered. The electric process is compared briefly with the Bessemer and open-hearth processes.—G. F.

The Theoretical Basis of Heat Production in High Frequency and Electric Arc Furnaces. F. Walter. (*Arch. Eisenhüttenwesen*, 1951, **22**, Nov.–Dec., 355–365). After a general review of the effect of heat on the state of aggregation of materials, the production of heat by alternating electromagnetic fields is discussed and the influence of frequency, permeability, and electrical conductivity of the material being heated on the energy taken up investigated. The electrical resistance of round and flat objects and the power they absorb from the electromagnetic field of a coil are calculated. Heat production in the electric-arc furnace is examined according to the pertinent physical laws and the effects of current conductors and the gas atmosphere on energy interchange in the arc are explained. The lack of uniformity in the arc energy in the three phases of an A.C. furnace is due to asymmetry in the coupling of the three low-voltage circuits.—J. P.

The Specific Electrical Conductance of Slags Containing Ferrous Oxide. W. A. Fischer and H. vom Ende. (*Arch. Eisenhüttenwesen*, 1951, **22**, Nov.–Dec., 417–423). The results previously obtained (*see J. Iron Steel Inst.*, 1951, **168**, May, 93) have been extended. The slags consisted of wüstite; fluorspar; FeO–CaO–Al_2O_3 with $CaO/Al_2O_3 = 1$; FeO–CaO–SiO_2 with $CaO/SiO_2 = 1{\cdot}6$ and $0{\cdot}6$; and FeO–CaO–Fe_2O_3; these were examined in the molten and solid states. After a critical examination of the effect of depth of melt in the iron crucible, depth of immersion and eccentricity of the iron electrode, the cell constant was determined with aqueous solutions of known conductance. The specific conductance of wüstite at 1400° C. was $7{\cdot}85$ ohm^{-1} cm^{-1}. It decreased with increasing SiO_2 additions to $0{\cdot}98$ ohm^{-1} cm^{-1} at 41 mole-% SiO_2. The values agreed well with those of Bockris and co-workers on MnO–SiO_2 slags. With the FeO–CaO–Al_2O_3 slags, the conductance at 1400° C. increased from $0{\cdot}266$ ohm^{-1} cm^{-1} at 11 mole-% FeO to $0{\cdot}94$ ohm^{-1} cm^{-1} at $31{\cdot}5$ mole-% FeO. There was a similar increase in the FeO–CaO–SiO_2 system. On increasing the FeO content from $17{\cdot}5$ to 28 mole-%, $CaO/SiO_2 = 1{\cdot}6$, the conductance at 1400° C. rose from $0{\cdot}5$ to $1{\cdot}06$ ohm^{-1}. cm^{-1}; an increase in FeO from 6 to 28 mole-%, with $CaO/SiO = 0{\cdot}6$, raised the conductance from $0{\cdot}076$ to $0{\cdot}47$ ohm^{-1} cm^{-1}. At a given temperature and FeO content, the acid slags were less conducting than the basic. The lime-bearing wüstite slags showed semi-conductance up to $31{\cdot}3$% CaO and the specific conductance was of the same order as that of pure wüstite. The accuracy of all measurements was $\pm$ 10%. The activation energies for conduction were determined from the temperature dependence of the specific conductance, in the liquid state, of all slags except those showing semi-conductance. They lay between $3{\cdot}4$ and 41 kg.cal. per mole. The energy of activation diminishes markedly with increased proportions of ferrous oxide.—J. P.

The Computation of Slag Equilibria. H. Flood. (*Tidsskr. Kjemi, Bergvesen Met.*, 1951, **11**, Nov., 146–150). [In Norwegian]. In order to apply the ideal law of mass action to slag-like systems, it is necessary to obtain the Lewis' activity values instead of concentrations. The activity can be computed from the phase diagram, electrometic measurements, or from investigations of simple chemical equilibria. Examples of these are given.—B. S. E.

Thermodynamic Calculations of Slag Equilibria. H. Flood and K. Grjotheim. (*J. Iron Steel Inst.*, 1952, **171**, May, 64–70). [This issue].

The Structure and Reactivity of the Oxides of Manganese. A. D. Wadsley and A. Walkley. (*Reviews of Pure and Applied Chemistry*, 1951, **1**, Dec., 203–213).

Influence of Shape and Maintenance on the Life of Steelworks Ingot Moulds. E. Folkhard. (*Berg- Hüttenmänn. Monatsh.*, 1951, **96**, Aug., 169–172). An analysis of the influence of shape, treatment in use, mould wall thickness, and length of idle period between stripping and pouring on mould life is made and illustrated by numerous graphs. Previous investigations are reviewed.—F. F.

The Influence of Constitution and Production Conditions on the Life of Steelworks Equipment. O. Kropf. (*Berg-Huttenmänn. Monatsh.*, 1951, **96**, July, 151–156). A literature survey and a report on experimental data relating to mould life as a function of mould material, mould shape, and method of use are given. So far, owing to the pronounced influence of conditions of use, which vary from works to works, only limited recommendations are advanced. These relate to homogeneity of the moulds and prevention of thermal and mechanical shocks.—F. F.

Graphite Inserts in Ingot Mould Bottoms. E. Boeckers. (*Stahl u. Eisen*, 1951, **71**, Nov. 22, 1314–1316). The advantages of graphite inserts in ingot mould bottoms are, according to results in the U.S.A., increased mould life and reduction of ingot sticking. Both these are of great importance in large integrated steelworks since changing of moulds and

delays when stripping ingots have a very serious effect on output. Experience at the Bochumer-Verein confirms American results.—J. P.

The Formation and Effect of Gas Cavities in Rimming Steel. R. L. Knight. (Australian Inst. Met.: *Australasian Eng.*, 1951, Nov. 7, 78–80). The author briefly outlines the macrostructure of a rimming steel ingot, and describes stage by stage the production of a full cast of such steel. The reactions occurring during the rimming process are outlined, and Hultgren and Phragmen's explanation of the mechanism of blowhole formation is discussed.—P. M. C.

Some Further Experiments with Rimming Ingots. D. Binnie. (*J. Iron Steel Inst.*, 1952, **171,** May, 71–74). [This issue].

Internal Structure of Killed Steel Ingots on the Basis of Relative Rates of Solidification. E. A. Loria. (*Blast Furn. Steel Plant*, 1951, **39.** Nov., 1333–1337). The control of internal soundness and segregation of killed steel ingots on the basis of rates of solidification is discussed. The longitudinal sections of some ingots of different shapes are critically examined. A description is given of the effects of the four components of heat abstraction, and possible changes in mould design are discussed with a view to accelerating vertical solidification, since a sounder ingot is produced if the vertical solidification core is wide rather than narrow.—J. P. S.

Causes of Formation of Different Types of Primary Structure in Steel During Crystallization. A. P. Pronov. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Tekhnicheskikh Nauk*, 1951, Apr., 576–578). [In Russian]. The factors influencing primary steel structure are briefly reviewed. The author's investigations of the crystallization of carbon steel are described. It is concluded that the formation of the primary structure of a dendritic or fine crystalline type is greatly influenced by the temperature of the liquid steel and freedom from crystallization centres.—V. G.

Harmful Inclusions in Certain Types of Special Steels. O. Krifka. (*Rev. Met.*, 1951, **48,** Dec., 895–911). Suitable refining of chromium steels for sheets in an acid induction furnace gives inclusions below 0·1 mm. in size and in a basic arc furnace below 0·04 mm. (the harmful size being about 0·25 mm.). Chromium–nickel steels can be refined by mixing with slag. Good polishing qualities become more difficult to obtain with lower carbon contents, owing to the increased amount of ferrous oxide.—A. G.

PRODUCTION OF FERRO-ALLOYS

More Titanium Oxide Now Available. D. I. Brown. (*Iron Age*, 1951, **168,** Nov. 1, 119–123; Nov. 8, 129–132). The mining operations at Havre St. Pierre, Canada, are described; this deposit, recently exploited, contains about 35% TiO_2 and 40% Fe. Smelting is carried out at Sorel about 550 miles further up the St. Lawrence. In this process an electric furnace 54 ft. long produces a slag containing 75% TiO_2 and liquid iron. The unit is of all-basic construction and operates under a slight pressure.—A. M. F.

Reclaiming Alloys from Tool Steel Mill Wastes. A. J. Schied, jun., and W. J. Mathews. (*Iron Age*, 1951, **168,** Nov. 8, 125–128). A procedure has been developed for refining alloy scale and grinding chips in a 6-ton top-charge electric furnace. The reducing agents used in refining are 75% ferrosilicon, calcium carbide, and ground coke, giving as products of reaction CO, CO_2, and SiO_2. All of the valuable alloys of tungsten, molybdenum, chromium, and vanadium are recovered in this way.—A. M. F.

Ferrochromium from Low Grade Ore Finds Wide Use. J. J. Grady. (*Iron Age*, 1951, **168,** Oct. 18, 95–98). The use of exothermic ferro-alloys of manganese, silicon, and chromium is discussed. The ferrochromium is made from low-grade ores by the Udy process and the exothermic reaction obtained in use gives chromium recovery in the open-hearth furnace as high as 95%. Exothermic ferromanganese can be added to the ladle to give specifications of more than 1% with 90–95% recovery.—A. M. F.

FOUNDRY PRACTICE

Productivity in the American and Norwegian Foundry Industries. J. Sissener and K. Stenstadsvold. (*Tekn. Ukeblad*, 1950, **97,** Dec. 28, 1001–1004). [In Norwegian]. The comparatively higher productivity in American foundries is explained by faster rate of work, better and more complete mechanization, and large-scale rational planning facilitated by mass production.—B. S. E.

Oxidation-Reduction Principles Controlling the Composition of Molten Cast Irons. R. W. Heine. (*Trans. Amer. Found. Soc.*, 1951, **59,** 121–138). A description is given of some laboratory experiments on the melting of cast iron. It was found that the basic principles of oxidation-reduction reactions established could be applied to air-furnace melting.—P. C. P.

Surface Quality of Parts Cast in Metal Moulds. A. S. Smirnov. (*Stanki i Instrument*, 1950, No. 4, 21). [In Russian]. The effect of the quality of mould surface on that of the part cast was experimentally investigated using 60 cast tensile test specimens.—S. K.

Investigations of the Mechanism and Kinetics of Fuel Combustion in a Cupola. L. M. Marienbach and J. S. Sucharczuk. (*Liteinoje Proizvodstvo*, 1951, No. 7; *Przeglad Odlewnictwa*, 1951, **1,** Dec., 342–344). [In Polish]. Results of the investigations of the influence of cupola blast velocity and temperature, and coke size on (1) the composition of combustion gases at the top of the combustion zone, (2) the change in the velocities of absorption of oxygen and reduction of CO_2, and (3) temperature distribution at the top of the combustion zone are presented. Experiments were made on the laboratory and industrial scales.—V. G.

Coke Charge and Coke Quality for Cupola Melting. W. von Preen. (*Gjuteriet*, 1951, **41,** Dec., 183–185). [In Swedish]. The unavoidable increase in coke consumption due to high CO content in the waste gas when using second-rate coke can be checked by increasing the wind volume and reducing the amount of iron in the charge, combined with adjustment of coke-bed height and coke rate.—B. S. E.

Basic Cupola Melting. E. S. Renshaw. (*Canad. Metals*, 1951, **14,** Aug., 30–38). Basic cupola melting favours desulphurization to low limits and gives high carbon pick-up in low-carbon charges. Details of the practice are discussed, including sulphur removal, silicon loss, carbon control, refractory technique, and water-cooling. Basic linings in the production of nodular iron are considered.—E. C.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Adequate Heating and Holding Times in Commercial Annealing and Heat-Treating of Steels. W. Hülsbruch. (*Stahl u. Eisen*, 1951, **71,** Nov. 8, 1219–1225). Commercial experience of adequate heating, holding, and cooling times in the annealing and heat-treating of steels is compared with statements in the literature, particularly with respect to grain size during austenitizing and embrittlement. Fast heating rates give fine grains. With faster heating, additional nuclei become operative. The minimum heating rate for production of fine grains varies from steel to steel. The fine-grained structure produced by rapid heating induces a displacement of embrittlement to lower temperatures, a higher strength, and less hardening rejects. The effect of heating rate explains the difference between laboratory and works heat-treatments, the difficulties of producing fine-grained structures in massive sections, and the superiority of continuous over batch furnaces. The use of three quenching baths in hardening has proved particularly useful in ensuring correct cooling rates. These consist of oil, water, and a mixture of 45, 45, and 10 parts of $NaNO_2$, KNO_3 and water respectively at 100–140° C. Rapid heating, short holding times, small temperature excess, and fine initial grain when austenitizing; exceeding the critical cooling rate when hardening; rapid heating, short holding time, highest possible temperature, and rapid cooling when tempering all have a favourable effect on the temperature of transition to brittle fracture. Grain coarsening resulting from cold work and temper brittleness has an adverse effect.—J. P.

Production Processes—Their Influence on Design—Heat Treating. R. W. Bolz. (*Machine Design*, 1951, **23,** Oct., 98–107). The most common treatments of steels are dealt with. Sections on conditioning processes, softening and hardening treatments, design considerations, specifications, carburizing steels, normalizing, surface hardening, case-hardening, and grinding are included.—E. G. S.

Continuous Production Assured with Batch Furnaces. G. Brailsford. (Machinist, 1951, **95,** Nov. 10, 1707–1708).

Production Heat Treating With Batch Furnaces. G. Brailsford. (*Steel Processing*, 1951, **37,** Nov., 569–571).

Batch Furnaces Achieve Continuous Production Rates. G. Brailsford.

(*Steel*, 1951, **129**, Dec. 3, 86–87). The author describes the furnaces and layout employed for continuous hardening and tempering of track-link bodies for tank treads at the Douglas Manufacturing Division of Kingston Products Company, Michigan. Eight 'Atmotrol' atmosphere muffle hardening furnaces and three tempering furnaces are used.—P. M. C.

How Metallurgical Control Solves Shop Problems. T. A. Frischman. (*Machinist*, 1951, **95**, Nov. 17, 1745–1760). The effects, origin, and prevention of heat-treatment and forging difficulties are dealt with. Special attention is given to irregularities in process procedures, application of preventive measures, and the use of boron steels. Solutions for some typical heat-treating problems are given.—E. C. S.

The Effect of Impurities and Alloying Elements in Steel. B. Weaver. (New Zealand Inst. Welding : *New Zealand Eng.*, 1951, **6**, Mar., 111–116). The article consists of a collection of definitions of heat-treating terms and iron–carbon alloy constituents, followed by brief summaries of the effects and functions of the main alloying elements.—P. M. C.

Metallography and Modern Heat-Treatment of Special Steels. A. Michel. (*Mét. Constr. Mécan.*, 1951, **83**, Nov., 853–861, 871). The author shows how metallographic research has produced new heat-treatments during recent decades. Isothermal annealing, martempering, austempering, sub-zero treatment, tempering, stabilization of austenite by ageing, and surface prestressing methods are discussed.—R. S.

Tool Steel Heat Treaters Can Profit from T-T-T Curves. L. H. Seabright. (*Iron Age*, 1951, **168**, Oct. 11, 101–105). It is shown that the time–temperature–transformation curves give valuable information on how to heat-treat tool and die steels. They show how to minimize distortion of water-hardening and oil-hardening steels, and the most practical way to cool high-speed steels in order to transform the austenite satisfactorily.—A. M. F.

Distortion of Tool Steels in Heat Treatment. J. Y. Riedel. (*Metal Treating*, 1951, **11**, July–Aug., 2–5 ; Sept.–Oct., 6–8). The causes of distortion and the difficulty of controlling it are discussed. The volume changes accompanying the various phase changes during heating and quenching are briefly outlined, and the behaviours of water-, oil-, salt-, and air-quenched steels are described. The treatment of cylinders, rectangular shapes, and rings is dealt with and specific heat-treatment cycles are described in which the shrinkage due to austenite formation is balanced by the expansion due to martensite formation.—P. M. C.

Parts Flattened by Annealing Under Weights. H. Chase. (*Iron Age*, 1951, **168**, Nov. 1, 134–136). Annealing under weights giving an applied pressure of about 1 lb./sq. in. replaces hand straightening of parts made from sheet or strip where close flatness limits are specified. Types of fixture used are simple but important.—A. M. F.

Stresses Imposed by Processing. O. J. Horger. (*SAE Quarterly Trans.*, 1951, **5**, July, 393–403). The author discusses thermal and transformation stresses developed in some heat-treating operations. The formation and measurement of such stresses are described, and the residual stresses existing in several rear axles of lorries are quoted. Fading of residual stresses due to repeated stressing (rotary fatigue testing) is also discussed. (27 references).—P. M. C.

Town Gas Serves Trafford Park. N. H. Greenway. (*Coke Gas*, 1951, **13**, Dec., 413–420). The industrial uses of gas in the area of the Stretford Undertaking of the N.W. Gas Board are described.—T. E. D.

Heat Treating the Carburizing Grades of Boron Steels. K. Rose. (*Mat. Methods*, 1951, **34**, Nov., 66–68). Avoiding excessive core hardenability, and obtaining satisfactory case hardness in large section parts, are the major problems in the treatment of boron steels. The author briefly discusses three methods of overcoming these difficulties, namely : changing the content of the alloying element (particularly manganese) ; reducing the carbon content ; and slowing the cooling rate by using salt-bath quenching. Several specific examples of these methods applied successfully are quoted.—P. M. C.

Gears Spun in Molten Salt Harden Teeth Only. W. F. Sorenson. (*Iron Age*, 1951, **168**, Nov. 8, 136–137). The problem of hardening the teeth on a drop-forged SAE 4140 steel gear to Rc 52 while maintaining a core hardness of Rc 36 has been overcome by the Yale and Towne Manufacturing Co. in the following way : The gear, immersed to a depth of about 1 in., is rotated in a cyanide salt bath maintained at 1525° F. and then quenched in oil at 150° F. and tempered. Scaling has been eliminated and distortion is extremely slight.—A. M. F.

The Nitriding of Castings of Iron or Special Steels Considerably Increases Their Resistance to Wear. R. Simonet. (*Usine Nouvelle*, 1952, **8**, Jan. 10, 25–26). Nitriding superficially hardens a number of special cast irons and steels, and involves heating the casting in ammonia. In the case of iron, a layer of unstable nitride is formed, which diffuses into the surface, and has no special hardening properties. With special steels, the nitrogen penetrates only a little, but, especially in the case of steel containing chromium or aluminium, combines to give stable nitrides in solid solution, which harden the surface considerably. Materials suitable for this treatment, and methods and temperatures used, are discussed. Uses of nitrided steels are summarized.—T. E. D.

Isothermal Hardening. H. Tauscher. (*Technik*, 1951, **6**, Sept., 406–411). Isothermal hardening is compared with quench-hardening. The effect of grain size and alloying elements on the position of the **S**-curve is discussed and hardenability, toughness, and wear resistance of the hardened steel are considered by reference to recent German literature and the author's own experiments.—J. G. W.

FORGING, STAMPING, DRAWING, AND PRESSING

Heavy Duty Mechanical Forging Presses. (*Engineering*, 1952, **173**, Jan. 25, 97–98). The extensive range of forging presses developed by B. and S. Massey, Ltd., Openshaw, Manchester, is described. (*See J. Iron Steel Inst.*, 1951, **170**, Feb., 171).

Some Common Causes of Tool Failure. (*Metal Treating*, 1951, **11**, Nov.–Dec., 4, 5). A very brief account is given of six failures of forging dies and other tools, traceable respectively to poor design, use of unmachined bar stock, effect of heavy steel stencil marks (two examples), poor surface finish in fillets, and slipshod heat-treatment.—P. M. C.

The Oldsmobile Forge Plant. J. C. McComb. (*Steel Processing*, 1951, **37**, Sept., 439–451, 467 ; Oct., 511–519). A complete description is given of the Oldsmobile plant, Lansing, Michigan, U.S.A., which produces 19,000,000 lb. of automobile forgings each month. The first part of the article deals with production flow, material handling, the press, upset and hammer shops, heating methods, the die-sinking department, and quality control. Part 2 describes the layout of the heat-treatment department, and includes details of the furnaces. Several treatments (of crankshafts, rear axles, and connecting rods), are described in detail. Pickling and shot-blasting facilities and inspection methods are described.—P. M. C.

British Experience with the Counterblow Forging Hammer. P. Granby. (*Steel Processing*, 1951, **37**, Nov., 562–566, 585). The author briefly outlines the limited use to which counterblow hammers have been put in Great Britain. The production of crankshafts weighing nearly 300 lb. on a 30,000 kgm. hammer at the English Steel Corporation's works, Sheffield, is described. Typical smaller components, produced with smaller hammers at the works of the Scottish Stamping and Engineering Co. Ltd., Ayr, and by Hughes-Johnson Stampings Ltd., Oldbury, are described.—P. M. C.

Heavy Crankshafts—The 'Continuous Fibre' Process. J. M. Vialle and J. Lafont. (*Mét. Constr. Mécan.*, 1951, **83**, Nov., 929–933). Changes in the initial ingot structure due to hot deformation are reviewed. The way in which the continuous-fibre (or R.R.) process allows for these changes is explained. The tooling equipment is described and illustrated.—R. S.

"RR" Process for Crankshaft Forging—Continuous Grain Flow and Metal Economy. (*Metal Treatment and Drop Forg.*, 1951, **18**, Dec., 557–558).

Blade Manufacture. V. N. Butler. (*Aircraft Prod.*, 1952, **14**, Jan., 19–20). Problems of design form are discussed in relation to cost and production. The merits of the forged gas-turbine blade are enumerated.—T. E. D.

Heavy Hydraulic Presses. (*Engineer*, 1951, **192**, Nov. 23, 670). A brief description is given of a 3600-ton hydraulic vertical plate-bending machine and of a 750-ton hydraulic flanging and joggling press manufactured at the Gloucester works of Fielding and Platt, Ltd.—M. D. J. B.

Design and Application of Tungsten Carbide to Blanking and Piercing Press Tools. K. L. Pickett. (*J. Inst. Prod. Eng.*, 1952, **31**, Jan., 31–61 : *Sheet Metal Ind.*, 1952, **29**, Feb., 129–143 : *Machinery*, 1952, **80**, Jan. 24, 165–167). This is a

review dealing with the basic principles of the subject, requisite presses, and design of several kinds of tools and their application to the razor blade, electrical, and other industries.—J. B. B.

Press Tools for Short-Run Production. T. W. Elkington. (*Sheet Metal Ind.*, 1952, **29,** Jan., 37–46, 50). The author discusses the need for short-run tools and the economic approach to their design and manufacture. Blanking, piercing, bending, and forming are all considered, and detailed drawings of typical tools are shown.—P. M. C.

Electronic Guard for Press Brake. (*Sheet Metal Ind.*, 1952, **29,** Jan., 48, 49). Brief details are given of a new installation at the works of J. H. Randall and Co. Ltd. When a beam of light is interrupted by the operator's arm entering the danger zone the press is automatically stopped.—P. M. C.

"Marform"—A New Metal Forming Process. (*Indust. Finishing*, 1952, **4,** Jan., 451–456). Tool research engineers of the American Glenn L. Martin Co. have recently developed a new metal-forming process called 'Marform.' It is claimed that formed sheet-metal parts can be produced at savings as high as 50%. The principal feature is the precision control for the forming cycle of the part. A substantial increase in the rate of production of numerous types of detailed parts and a considerable decrease in labour and tooling costs can be achieved.—H. F.

The Working of Metals. W. C. F. Hessenberg. (*Metal Ind.*, 1952, **80,** Jan. 11, 23–25). The author describes briefly how plasticine models are being used by B.I.S.R.A. to investigate the internal strains produced by various metal-shaping operations. Wire drawing, extrusion, and forging are all briefly discussed.—P. M. C.

What To Do About Wrinkled Stampings. T. A. Dickinson. (*Steel Processing*, 1951, **37,** Oct., 499–500, 533). The formation of wrinkles in the fabrication of sheet stock by the Guerin process has been almost entirely eliminated at North American Aviation Inc., Los Angeles. Sheet-metal clips are attached round the edges of the sheet-metal blanks and serve to equalize forming pressures. A pneumatic hammer and a pneumatic slapper have also been designed to eliminate the tedium of hand work when wrinkle removal is unavoidable.—P. M. C.

Determination of Intermediate Sizes in Drawing on a Multiple-Draw Machine. K. Schemmer. (*Arch. Eisenhüttenwesen*, 1951, **22,** Nov.–Dec., 367–370). A minimum value of reduction in cross-section for each stage on a multiple-draw machine is fixed by the ratio of the drawing speeds of two adjacent sheaves. Continuous machines with variable sheave speed are not considered. Mathematical and graphical procedures to ascertain the correct sizes of a group of dies for producing a given overall reduction are given.—J. P.

Drawing Capacity and Power Consumption in the Two-Bar Drawing Process. A. Mackert. (*Stahl u. Eisen*, 1951, **71,** Oct. 25, 1156–1160). The drawing capacity of a bar-drawing bench has been trebled by reconstructing it on the two-bar principle and installing automatic gripping and removal of the bars, and return of the drawing carriage. The operation of this carriage is described. Measurements on a series of materials when using single and two-bar drawing have shown that the latter process consumes 1·8 times as much power as the former.—J. P.

Mullins Develops New Cold Extrusion Process. (*Steel Processing*, 1951, **37,** Oct., 505, 519). The virtues and achievements of the 'Koldflo' process, developed by the Mullins Manufacturing Corp., U.S.A., are briefly outlined. No details of its operation are given.—P. M. C.

Hot Extrusion of Steel. J. Sejournet. (*Mét. Constr. Mécan.*, 1951, **83,** Nov., 889–891). The work of the Comptoir Industriel d'Etirage and the Aciéries Electriques d'Ugine in developing the hot extrusion of steel is briefly described and the advantages of this process are explained. Applications mentioned include the production of tubes square outside and round inside, and tubes with tapering inside and constant outside diameters.—R. S.

Cracking of Steel Wires during Reduction. W. Püngel. (*Stahl u. Eisen*, 1951, **71,** Oct. 25, 1137–1140). The cracking of steel wires, superficially and internally, which occurs on reduction in a revolving hammer mill, is not due to defective material but to lack of synchronization in the rates of revolution of the wire and the hammers. Cracking no longer occurs when the rates are equalized.—J. P.

An Impression Technique for Measuring Die Profile. H. Schmidt. (*Stahl u. Eisen*, 1951, **71,** Oct. 25, 1161–1162). The use of dental copper amalgam for taking impressions of drawing dies is described.—J. P.

Design and Measurement of Drawing Die Profiles. V. Domes. (*Stahl u. Eisen*, 1951, **71,** Oct. 25, 1147–1148). A method is described for measuring die profiles. This depends on pulling a wire partly through the die and then removing it carefully. The specimen is mounted vertically, a narrow slit beam of light projected horizontally on to it and the angle between the incident and reflected beam measured. The specimen is moved vertically by a micrometer screw and the die angle measured after successive small movements. As a result of such measurements a new die profile has been developed. This is of 'bell' shape, the lead-in being concave and the exit convex.—J. P.

ROLLING-MILL PRACTICE

Comparison Beween British and American Rolling-Mill Practices. G. Foster (*J. Iron Steel Inst.*, 1952, 171, 87–91). [This issue].

The Structures of Cast Iron Rolls. J. Jastrzebska. (*Prace Glownego Instytutu Met.*, 1951, **31,** 6, 463–489). [In Polish]. To obtain metallurgical criteria for the quality of rolls, surface structure of rolls and statistical data of their wear in practice were investigated. On the basis of these investigations the best type of surface structure was established and some recommendations as to measures required to obtain improved structure are given.—V. G.

The Choice of Electrical Main Drives for Steel Rolling Mills. N. R. D. Gurney. (*Metr. Vick. Gaz.*, 1951, **23,** May–June, 363–368; 1951, **24,** July–Aug., 12–24). The first step is to decide the capacity of the drive needed; the information required is listed. The method of calculating the horsepower needed for each pass is described. Two ratings have to be decided: the maximum operating peak and the continuous or heating (R.M.S.) rating. Generally speaking, if a constant fixed-speed drive is required, an A.C. motor is the most suitable. If the drive is required to operate over a wide speed range or (for large motors) to be accelerated and decelerated to rest at frequent intervals, a D.C. motor fitted with Ward-Leonard control is the most suitable. Different designs of electric motor available are compared.—B. G. B.

Alan Wood Steel Installs Mill Scale Recovery Plant. R. F. Coltart. (*Iron Steel Eng.*, 1951, **28,** Nov., 128). A brief description is given of an industrial waste-treatment plant recently put into operation by the Alan Wood Steel Co., Ivy Rock, Pa. The plant treats and recirculates cooling water from the company's blooming mill, plate mill, and strip mill operations.—M. D. J. B.

Rails and Rail Fittings. J. R. Zadra. (*Amer. Iron Steel Inst. Regional Meeting*, 1951). The author traces the history of the railway rail, and describes the developments in design and rolling practices made to meet the increasing speeds and loads. Some defects encountered and methods of avoiding them are discussed.—G. F.

Rail Production. A. G. Hock. (*Railway Steel Topics*, 1951, **1,** 1, 4–6). A brief description is given of the sequence of developments of rail-steel production at the various branches of The United Steel Companies, Ltd.—H. F.

Steel Rails. W. K. Wallace. (*Railway Steel Topics*, 1951, **1,** 1, 9–18). The development of rails since 1630 is traced through the origins of double-headed rails, the adoption of bull-head sections, and the beginnings of standardization to flat-bottom rails. Other features discussed are: Changes in composition of the steel; effect of work hardening on the rails; a comparison with American practice; modern practice with regard to rail joints; and the problem of corrosion.—H. F.

Solid Rolled Steel Wheels. C. F. Ryan. (*Railway Steel Topics*, 1951, **1,** 1, 25–27). A complete description is given of the manufacture of solid rolled steel wheels from the ingot to the finished article before machining, in the plant of Steel, Peech and Tozer, Rotherham.—H. F.

Cold-Reduction Sheet Mill at Pittsburg, California. (*Engineering*, 1951, **172,** Dec. 21, 769–771). A description is given of a new cold-reduction sheet mill at Pittsburg, California. The mill is of the five-stand four-high tandem type and has a finishing speed of 3900 ft./min. Detailed technical and operational information is given of the mill and its subsidiary equipment. The mill has a capacity of about 450 tons of strip per 8-hr. shift. Steel strip for tinplate passes through one of two four-high two-stand tandem temper mills at about 3000 ft./min. and is supplied in widths of 16–38 in.—M. D. J. B.

Magnetic Amplifier Control for Rolling Mills. (*Iron Steel Eng.*, 1951, **28,** Nov., 112–114, 118–120). A description is given of the 'Magamp' magnetic amplifier and of its application in all types of control and regulating circuit in practically every electrified industry in the U.S.A., including the control of individual-generator tandem cold-reduction mills.

A Steel Plate Thickness Meter. S. S. Carlisle and B. O. Smith. (*Engineer*, 1951, **192,** Dec. 21, 805–808). A portable magnetic instrument for measuring the thickness of steel plates, requiring access to one side only and employing a magnetic method, is described. The measuring head consists essentially of a pot-shaped electromagnet which indicates the total magnetic flux in the main magnet circuit. When it is applied to the plate, saturation flux density is produced in the body of the plate and the total flux indicated is directly related to the plate thickness.—M. D. J. B.

MACHINERY FOR IRON AND STEEL PLANT

Mechanical Engineering in the Iron and Steel Industry. W. F. Cartwright. (Joint Eng. Conf.: *Brit. Eng.*, 1951, **34,** Nov., 186–191). This review of mechanical progress in the iron and steel industry includes not only the mechanical engineer's contribution but also what the future might hold. Much steelworks equipment is described and illustrated.—H. F.

Oil-Hydraulic Equipment. E. A. Berglund. (*Iron Steel Eng.*, 1951, **28,** Nov., 75–80). The principles and fundamental notions of hydraulics are stated and how these can be applied to the hydraulics of oils is discussed. Simple oil-hydraulic machines are described, oil circuits given, and the numerous applications are considered.—M. D. J. B.

Hydraulic Scrap Metal Baling Presses. (*Metallurgia*, 1951, **44,** Nov., 261). A description is given of the 'Fielding' hydraulic single-compression scrap metal baling press, which is suitable for baling ferrous and non-ferrous clippings from sheet metal, waste drums, and cans. An output of up to 3 tons/hr. (30 bales) can be achieved.—J. B. B.

Handling Iron and Steel with Electric Magnets. D. Amies. (*Mech. Handling*, 1952, **39,** Feb., 52–56). Brief consideration is given to the correct choice of magnet. The uses and advantages of circular, rectangular, and bi-polar magnets are given.—D. H.

Cranes and Lifting Machinery. P. B. Hebbert. (*J. Junior Inst. Eng.*, 1952, **62,** Jan., 127–139). The three-motion overhead electric travelling crane is the most easily adaptable and most widely used for indoor services. A description is given of the framework design and the electrical and winding mechanisms.—B. G. B.

Plastics *versus* Metals in Bearings. R. H. Warring. (*Mech. World*, 1952, **131,** Jan., 27–28). Details are given of the use of thermo-setting or resin plastics in bearings. These plastics when suitably prepared have mechanical properties akin to those of metals. Useful working data are presented.—D. H.

LUBRICANTS AND LUBRICATION

Lubrication of Enclosed Gears Subject to Chronic Water Conditions. J. A. Rigby. (*Iron Steel Eng.*, 1951, **28,** Nov., 73–74). Consideration is given to some of the lubricating problems involved in rolling plate, sheet, and strip where large volumes of water are used in cooling and descaling. The author discusses the merits of recently developed solvent lubricants prepared so as to have extremely high film strength and good adhesion.—M. D. J. B.

Filtration of Lubricating and Cooling Oil in Wire Drawing and Strip Rolling. H. C. Smith, jun., and G. Zebora. (*Wire and Wire Products*, 1951, **26,** Sept., 762–763 788–789). A filtration system is described for removing metal dust and dirt from wire-drawing lubricants. This system is built around a pressurized vessel containing a filtering mat and the use of filtering aids, *e.g.*, diatomaceous earth. Data are given of the performance of a large installation in a mill producing stainless steel and other high-alloy wires. Filters are replaced bi-monthly, the original oil retaining its lubricating qualities for two years. A similar system has been installed on a Sendzimir rolling mill.—J. G. W.

WELDING AND FLAME-CUTTING

Quality Problems with the Submerged Arc Welding Process. M. Komers. (*Stahl u. Eisen*, 1951, **71,** Nov. 8, 1225–1232). By correct choice of welding powder and welding rod, welds can be made which have a strength factor of 1·0. The applicability of submerged-arc welding (Ellira method) has been tested on many specimens of alloyed and unalloyed steel plate up to 110 mm. thick. The characteristic crystallization in the middle of the weld influences the impact and tensile strengths in the as-welded condition. Annealing at 650° C. or normalizing removes this defect. When welding thicker plates, the double-head method has marked advantages over the usual two- or multi-layer welding. Non-destructive testing methods are discussed.—J. P.

Cast-Weld Design. (*Machine Design*, 1951, **23,** Oct., 137–140). Examples of parts made of castings welded together selected from the files of the Steel Founders' Society of America are given.—E. C. S.

A New Proposal for Steel Filler Wire for Welding. H. Sekiguchi. (*Welding J.*, 1951, **30,** Dec., 622s–624s). For welding mild steel a new steel filler wire is used containing silicon and manganese as deoxidizing elements. When the welded part is cooled rapidly, however, the silicon content of the filler wire should be below 0·3%.—U. E.

Sigma Welding of Carbon Steels. H. T. Herbst and T. McElrath, jun. (*Welding J.*, 1951, **30,** Dec., 1084–1091). The advantages of using argon–oxygen mixtures for 'sigma' (shielded inert gas metal arc) welding of carbon steels are discussed. Mechanical properties of mild-steel weld metal are given.—U. E.

Shielded Arc Welding of Aluminium and Stainless Steel. G. Pettit. (*Canad. Metals*, 1951, **14,** Aug., 52–56). A description is given of the use of inert-gas-shielded arc methods for welding stainless steel and the fabrication of high-tensile aluminium alloys.—E. C.

Dilution and Diffusion Aspects of Non-Fusion Welding. R. D. Wasserman and J. Quaas. (*Welding J.*, 1951, **30,** Dec., 1098–1101). Non-fusion welding is defined as the bond between the brazing metal and the base metal and is obtained by a diffusion of the filler metal into the base material and by surface alloying of the base metal and filler material. The Hume-Rothery law of dilution is discussed and a mathematical treatment of Fide's law of diffusion is given.—U. E.

Low-Temperature Welding Methods and Applications. E. J. Raymond. (New Zealand Inst. Welding: *New Zealand Eng.*, 1951, **6,** May, 191–194). The author discusses several brazing techniques, and outlines the separate applications of bead-forming and film-forming filler alloys.—P. M. C.

Modern Welding Developments. E. J. Raymond. (New Zealand Inst. Welding: *New Zealand Eng.*, 1951, **6,** June, 233–235). The following processes are briefly described: Oxygen machine cutting, deseaming, flame gouging, flame hardening, and aluminium and argonarc welding.—P. M. C.

Repairing of Hardened Steel Gears by Welding. A. H. Barltrop. (New Zealand Inst. Welding: *New Zealand Eng.*, 1951, **6,** May, 189, 190). A brief outline is given of a procedure whereby a chromium–molybdenum welding rod is used to build up worn gear teeth.—P. M. C.

Welding Repair of Forging Equipment. J. M. Wilson. (*Steel Processing*, 1951, **37,** Oct., 501–504, 533). Many successful repairs accomplished in the forging industry indicate that the thermit welding process offers a safe and economical method of putting equipment back into service quickly, economically, and permanently. The thermit welding process is described, and several examples of welds on large hammer columns, die slides, and rams are described and illustrated.—P. M. C.

Improvement of Inert-Gas Welding by Using High-Purity Helium. W. A. Mays. (*Welding J.*, 1951, **30,** Dec., 602s–606s). The helium-shielded arc-welding process produces sound non-porous welds on aluminium, magnesium, and stainless steel. If the helium is contaminated with even minute quantities of gases, such as oxygen, nitrogen, hydrogen, water vapour, or oil vapour, aluminium welds are inferior.—U. E.

Hydrogen in Brazing and Welding. R. H. Warring. (*Mech. World*, 1951, **130,** Dec. 21, 567–570). A short survey is given of welding, brazing, and soldering. The atomic hydrogen welding process is discussed together with the use of a hydrogen atmosphere in furnace brazing.—D. H.

Town Gas as a Fuel in the Engineering and Metal Industries. I. Eneborg. (*Tekn. Tidskr.*, 1951, **81,** Dec. 8, 1057–1060). [In Swedish]. Applications of town gas in the metallurgical industries are outlined. The use of gas and oxygen for cutting, flame-hardening, and welding is described.—B. S. E.

Microcracks and the Low-Temperatures Cooling Rate Embrittlement of Welds. A. E. Flanigan and M. Kaufman. (*Welding J.*, 1951, **30**, Dec., 613s–622s). Welds were deposited on semi-killed $\frac{3}{4}$-in. steel plate (0·19% C, 0·33% Mn, 0·07% Si, 0·03% S, 0·015% P). Inferior welds are usually attended by the appearance of fine microcracks in the interior of the weld. Methods for detecting them are described. The suspicion that microcracks, though unrecognized, may frequently occur in welding practice has been supported by observations on a multipass butt weld. There is evidence that hydrogen is a prime factor in the mechanism of embrittlement.—U. E.

Fatigue Strength of Panels with Welded Angle Stiffeners. R. Week. (*Welding Res.*, 1951, **5**, Oct., 219r–249r). Fatigue tests by the resonance method have been carried out on 66 specimens consisting of a steel plate 10 ft. × 2 ft. × $\frac{5}{16}$ in. stiffened with two welded-on or riveted-on angle or channel stiffeners, incorporating various welded details and joints. The stress distribution in the specimens was determined by electric resistance strain gauges, both in the longitudinal direction of the specimen for its whole length and for the central cross-section where the bending stresses were at a maximum. The effectiveness of several different types of reinforcing strap was investigated.—U. E.

Loading Capacity of Fatigue-Stressed Welded Girders. F. Faltus. (*Strojirenstvi*, 1951, **1**, May, 170–172). [In Czech]. It is shown that the repair of damaged girders by local welding may greatly reduce the fatigue strength unless special care is taken. Examples of repaired bridge girders are quoted.—E. G.

Fatigue Strength of Welds in St. A 37 Made with Ferrimantle Type Electrodes. (*Lastechn.*, 1951, **17**, Dec., 192–195). [In Dutch]. Fatigue tests on the Losenhausen pulsator are described. The results for St. A 37 welds are given. Ferrimantle-type electrodes were used for welding. Fatigue stresses between zero and the maximum tensile stress were applied.—R. S.

Flash Butt-Welder for Steel Strip. (*Engineering*, 1951, **172**, Dec. 28, 820). A description is given of a flash butt-welding machine constructed by the British Federal Welder and Machine Co. Ltd. and operating in the pickling line at The Steel Company of Wales at Llanelly. It can deal with steel strip up to a maximum width of 48 in. and a thickness of 0·15 in. and is designed to complete and trim a weld in a maximum cycle time of 90 sec. from start to finish. The machine is approximately 20 ft. long, 15 ft. wide, and 10 ft. high and weighs about 70 tons.—M. D. J. B.

Temperature Distribution During the Flash Welding of Steel. E. F. Nippes, W. F. Savage, J. J. McCarthy, and S. S. Smith. (*Welding J.*, 1951, **30**, Dec., 585s–601s). The flashing portion of the flash-welding process was investigated using SAE 1020 steel in various section sizes. Measured temperature distributions were employed as criteria for comparison of the effect of individual flashing variables for two general types of flashing pattern. Parabolic flashing was found to establish a stable temperature gradient with 55% less 'burn-off' per specimen than was required with linear flashing. Increasing platen acceleration, increasing specimen thickness, and decreasing initial clamping distance, produced steeper stable temperature gradients. The secondary welding voltage and the specimen width had no effect on the stable temperature distribution during flashing.—U. E.

Magnetic Particle Inspection of Welded Pipe and Tubing. J. E. Clarke, R. A. Peterson, and T. J. Dunsheath. (*Non-Destructive Test.*, 1951, **9**, Spring, 7–13). A brief outline of resistance-welding techniques and inspection needs is given, followed by an account of early magnetic inspection developments. Operating data are then described for both inside and outside yoke units which have been developed by the Magnaflux Corp.—P. M. C.

Processes Used in the Bonding of Metals by Means of Synthetic-Resin Adhesives. F. H. Parker. (*Sheet Metal Ind.*, 1952, **29**, Jan., 63–68). The 'Redux' process for metal bonding is described, with special reference to light metal airframe structures. The peeling test as developed by Aero Research Ltd., is described.—P. M. C.

Influence of Flame-Cutting on the Quality of Low-Carbon Boiler Steels. R. Krňák. (*Strojirenstvi*, 1951, **1**, June, 210–212). [In Czech]. On the basis of test data the author finds that in the making of welded boilers and pressure vessels of steel with carbon less than 0·35% it is not necessary to machine the frame-cut edges, provided these are left clean and smooth.—E. G.

Oxygen Cutting and Powder Cutting Methods. (*Usine Nouvelle*, 1951, **7**, Dec. 20, 47). Because of the additional supply of calories provided by the burning of iron powder on the surface being cut, powder cutting is very much more rapid than ordinary oxygen cutting. Applications of the method are summarized.—T. E. D.

Use of Oxy-Acetylene In Pipe Fabrication. E. P. Auler. (International Acetylene Assoc.: *Steel Processing*, 1951, **37**, Nov., 555–559). Sources and methods of distribution of oxygen and acetylene are outlined, and general applications of cutting and gouging torches are described.—P. M. C.

Oxy-Cutting of Cast Iron, Stainless Steel and Other Cast Alloys. I. Aversten and C. Scharfhausen. (*Ciencia y Tecn. Soldadura*, 1951, **1**, July–Aug., 943). [In Spanish]. The problems of oxygen-cutting cast iron, stainless steel, and other alloys are discussed and the method involving injection of iron powder into the gas stream is described.—R. S.

CLEANING AND PICKLING

Operation and Results Obtained with a Wire Descaling Machine. W. Zwierz. (*Stahl u. Eisen*, 1951, **71**, Oct. 25, 1133–1135). The development and operation of a French wire descaling machine are described. Descaling is effected by passing the wire over two pulleys rotating in planes at right-angles and then submitting it to the action of a pair of wire brushes revolving in opposite directions. The housing of the brushes rotates round the wire. The drawing results obtained are as satisfactory as with pickled wire, but the fact that the wire now runs straight from the descaling machine into the first drawing die without any 'whip' makes conventional lubricants inadequate and die wear excessive. The use of dry proprietary lubricant enabled this drawback to be overcome.—J. P.

Abrasive Belts for Polishing. J. F. Whitcomb. (*Metal Finishing*, 1951, **49**, Aug., 46–48). The increase in metal finishing rates and savings in costs at six works are illustrated. The equipment for, and mode of operation of, back-stand belt grinding are briefly described.—J. P.

The Electric Multiple-Motor Drive of Monorail-Wheelabrators. O. Schoch. (*Brown Boveri Rev.*, 1951, **38**, May–June, 183–188). A brief description is given of the construction, mode of operation, and essential features of the electrical equipment of a modern, high-capacity machine for cleaning castings with shot or grit.—B. G. B.

Measures to Improve Efficiency in Bright-Drawn Steel Bar Pickling Shops. F. von der Heide. (*Stahl u. Eisen*, 1951, **71**, Oct. 25, 1148–1153). The effect of temperature and H_2SO_4 and HCl concentrations on the rate of removal of scale from a variety of steels is discussed. Laboratory tests emphasize the advantage of submitting the steel to the action of a scale-breaker before pickling.—J. P.

Cleaning and Preparation of Metals for Electroplating. III—Degreasing Evaluation Tests: The Atomizer Test. H. B. Linford and E. B. Saubestre. (*Plating*, 1951, **38**, July, 713–717; Aug., 847–855). An investigation, has been carried out to find a suitable method for determining the cleanliness of degreased metal. In the atomizer test, the cleaned panel is allowed to dry and then sprayed with an aqueous blue dye solution. On clean areas the metal is wetted uniformly, but soiled areas are covered with small globules. The sample is dried by radiant heat and the pattern 'frozen.' Where the metal was wetted, the dye is too dilute to leave much stain on drying, so that the soiled portions show up as spotted areas. The theory underlying all wettability tests is discussed with reference to the great sensitivity of the atomizer test.—J. P.

Materials of Construction for Pickling Operations Prior to Electroplating. E. A. Tice. (*Plating*, 1951, **38**, Aug., 826–830). The effects of various pickling and bright-dipping solutions on materials of construction for tanks, baskets, barrels, and heating coils are discussed. The author indicates suitable materials for fabricating these articles.—J. P.

Magnetic Device Improves Continuity of Pickling Line Operation. W. W. Palmer. (*Steel*, 1951, **129**, Dec. 3, 96–108). A control system for regulating the height of a loop of steel strip in a pickling tank to permit it to run close to the bottom without dragging is described. The detector unit used is an acid-proofed magnetic core which is affected by the distance between the loop and the bottom of the tank.

Investigation of Some Pickling Inhibitors. S. A. Balezin and S. K. Novikov. (*Zhurnal Prikladnoy Khimii*, 1951, **24**, 3, 283–288). [In Russian]. The use of formaldehyde, hexamethylene tetramine, and thiodiglicol as inhibitors in acid pickling of steel was investigated.—V. G.

Basic Principles of the Pickling and Etching of Steels and Their Application to the Production of Stainless-Steel Sheet. H. E. Zentler-Gordon. (*Sheet Metal Ind.*, 1952, **29**, Jan., 5–10, 16). The author gives a brief survey of the methods and mechanism of the pickling and etching of steel, and also details of a new phosphate-base electrolytic treatment for the elimination of surface defects.—P. M. C.

Cleaning with Sound Waves. J. Starr. (*Products Finishing*, 1951, **16**, Nov., 52–56). The application of ultrasonic generators (electrostrictive and magnetostrictive transducers) to alkali detergent baths to speed up cleaning is briefly described.—J. P.

Stripping of Electrodeposits. R. H. Keller. (*Commonwealth of Australia, Defence Research Laboratories Information Circ.* 16, Sept., 1951). This 23-page booklet collects in handy form the published methods for stripping brass, bronze, cadmium, chromium, copper, gold, lead, nickel, palladium, platinum, rhodium, silver, speculum, tin, and zinc from the base metals on which they are usually plated.

Pickling for Porcelain Enamelling. I—The Spray Pickling Process at Kaiser Metal Products, Incorporated. A. E. Blount. (*Products Finishing*, 1951, **15**, Sept., 12–15). The fully automatic conveyor system for treating sink tops and bath tubs is described. All solutions are applied by spray. The articles are freed from grease by emulsion and alkali cleaners pickled in 8% H_2SO_4 at 160° F., treated with nickel sulphate solution, neutralized, and dried.—J. P.

Pickling for Porcelain Enamelling. II—Pickling with Troxide at the Estate Stove Company. F. L. Bonem. (*Products Finishing*, 1951, **15**, Sept., 18–22). Steel range and heater parts are cleaned and pickled before porcelain enamelling in a series of tanks arranged for efficient handling and straight-through flow. Acid sulphate salts, known as Troxide Compounds, are used instead of sulphuric acid in the pickling operation.—J. P.

De-Enameling Process Economically Reclaims Defective Enameled Ware. K. Rose. (*Mat. Methods*, 1951, **34**, Nov., 80, 81). The stripping off of imperfect vitreous finishes in a strong caustic soda solution held at 300° F. is briefly described. After washing, sand blasting, and drying, the salvaged articles are ready for re-enamelling.—P. M. C.

Waste Treatment in The Modern Steel Mill. J. E. Cooper. (*Iron Steel Eng.*, 1951, **28**, Nov., 81–84). A survey is given of the principal waste and effluent problems occurring in the iron and steel industry. Phenol and spent pickling acid are the wastes most commonly associated with steel plants, but to these must be added oil, cyanide, flue dust, mill scale, ammonia, naphthalene, and metal-finishing wastes in varying amounts. The author suggests that all effluent be passed through a simple treatment plant of a type which is giving good results at the Ford Motor Co., the Alan Wood Steel Co., the Armco Steel Corp., and the U.S. Steel Co.—M. D. J. B.

Determination of Small Amounts of Cyanide in Polluted Water. I. Nusbaum and P. Skupeko. (*Metal Finishing*, 1951, **49**, Oct., 61–63). By means of a modified pyridine–benzidine reaction with cyanogen bromide, formed by adding bromine water to the cyanide solution, free cyanide can be determined directly in sewage and polluted waters in the range 0·02–0·5 p.p.m. with reasonable accuracy and little interference. The test is made more sensitive by extracting the orange-coloured complex with butyl alcohol.—J. P.

PROTECTIVE COATINGS

Substitute Finishes For Electroplating. Phosphate Coatings. A. Douty. (*Plating*, 1951, **38**, Oct., 1030–1033). The types and thicknesses of phosphate coatings applied to various steel, zinc, cadmium, and aluminium surfaces, methods of application, supplementary treatments, and salt-spray resistances are given in tabular form.—J. P.

Substitute Finishes for Electroplating. Chromate Treatments. C. W. Ostrander. (*Plating*, 1951, **38**, Oct., 1033–1035). The corrosion resistance of zinc, cadmium, and aluminium as castings, etc., or as coatings, is increased if they are given a chromate coating. The methods by which this type of protection may be applied and the precautions to be taken in processing are described.—J. P.

Substitute Finishes for Electroplating. Black Oxide Coatings on Metals. W. R. Meyer. (*Plating*, 1951, **38**, Oct., 1036–1037). The methods by which black oxide coatings may be produced on iron, steel, stainless steel, copper, zinc, cadmium, and aluminium are briefly described. Most methods employ aqueous solutions or fused mixtures of salts containing oxidizing agents. Others depend on depositing metals or oxides from nickel, molybdate, or chromate solutions. These coatings are applied for low reflectivity, colour contrast, economy of application, reduction of friction, etc., but do not possess any appreciable corrosion resistance.—J. P.

Substitute Coatings for Electroplating. Organic Coatings in Today's Metal Finishing. D. R. Meserve. (*Plating*, 1951, **38**, Oct., 1037–1039). The use of clear and tinted lacquers to protect chromium, applied direct to steel because of shortage of copper and nickel, and bright zinc against corrosion is discussed generally.—J. P.

Substitute Finishes for Electroplating. Rust Preventatives—A General Survey. A. W. Ackerman. (*Plating*, 1951, **38**, Oct., 1047–1051). The use of temporary rust preventatives is discussed. Methods of application and corrosion resistance of some typical materials are described.—J. P.

Porosity of Electrodeposited Metals. X—Hydrogen Content of Electrodeposited Metals. N. Thon, D. G. Kelemen, and Ling Yang. (*Plating*, 1951, **38**, Oct., 1055–1058). Results of degassing experiments at different temperatures on foils of electrodeposited nickel, copper, chromium, and iron are reported. Hydrogen can be present in such foils in three forms. The first is a labile supersaturated form which is released very readily even at room temperature. The second is co-deposited and is very tenaciously held; heating to above 550° C. is necessary to drive it out. It is suggested that this hydrogen is present in atomic form and is incorporated, during the growth of the deposit, at highly active sites. The third is electrolytically incorporated and is due to hydrogen taken up by the ready-made foil by cathodic charging with hydrogen in a suitable electrolyte. It is claimed that the amount of co-deposited hydrogen depends on the nature of the substrate upon which the foil is deposited and on the amount of current previously passed through the bath. Copper takes up practically no hydrogen but chromium and iron can take up large amounts.—J. P.

Methods for Testing Thickness of Electrodeposits. III—Comparison of Methods for Acid Copper on Steel. H. J. Read and F. R. Lorenz. (*Plating*, 1951, **38**, Sept., 945–952, 958). Acceptable thickness standards for acid copper on steel can be produced easily with a simple electrolytic cell. The reproducibility of the General Electric thickness gauge (Model A), the Magnegage, the Lea Lectromag, the B.N.F. jet test, the microscopic method, and the stripping method is adequate for most purposes.—J. P.

Electroplating Stainless Steel. A Critical Review with Recommended Practices. J. Haas. (*Metal Finishing*, 1951, **49**, June, 50–54). Data based on experience in plating various types of stainless steel are presented and previous methods are critically reviewed. There is no difficulty in plating stainless steel if it has been previously activated by cathodic treatment in HCl or H_2SO_4.—J. P.

Electrographic Non-Destructive Identification of Metallic Materials. A. Fiala. (*Strojirenstvi*, 1951, **1**, May, 169). [In Czech.] A simple method of identifying plated coatings and welding electrodes is described. It is based on forming a cell with the metal to be identified as anode, an aluminium cathode, and a filter paper soaked with a suitable chemical as the electrolyte.—R. A. R.

Thickness Meters—Some Applications. (*Indust. Finishing*, 1951, **4**, Dec., 404–405). A description is given of the applications, methods of use, and general details of the portable Marconi thickness meter TF884 which will operate on coatings between 0·0001 and 0·01 in. thick, provided they are non-magnetic and on a magnetic base.—H. F.

Finishing Army Ordnance Materiel. G. T. Viglione. (*Metal Finishing*, 1951, **49**, July, 89–91, 114, 115). The use of phosphate coatings and cadmium, zinc, and chromium plating to protect steel ordnance components against corrosion and abrasion, and of anodizing to protect aluminium against corrosion is described.—J. P.

Disposal of Plating Room Wastes. III—Cyanide Wastes. Treatment with Hypochlorites and Removal of Cyanates. B. F. Dodge and W. Zabban. (*Plating*, 1951, **38**, June, 561–586). It is shown that cyanides can be oxidized com-

pletely to cyanates by chlorine water, sodium hypochlorite, or calcium hypochlorite in less than 5 min. at room temperature unless nickel is present, when 30 min. are required. Oxidation of cyanates by hypochlorites to carbon dioxide and nitrogen is complete in 1 hr. at room temperature. The best conditions for carrying out these reactions are given.—J. P.

A Proposal for the Control of Hard-Chromium Baths. G. Dehmel. (*Metalloberfläche*, 1950, **2,** July, B105–B106). It is suggested that the total current consumption in the plating bath be recorded, as it is indicative of the chromium loss. After each 1% reduction of chromium content a sample of the liquid is analysed, and the composition of the electrolyte is recorded, CrO_3, Cr_2O_3, H_2SO_4, or H_2SiF_6 being estimated.

Hard Chrome Plating—The Industrial Workhorse. J. A. Williams. (*Metal Finishing*, 1951, **49,** July, 100–102, 120). The application of thick chromium deposits for resistance to wear and corrosion on military equipment and on working tools is discussed.—J. P.

Surface Refinement by Metal Diffusion. H. Baukroth. (*Technik*, 1951, **6,** Nov., 493–496). This is a progress report on research by an organization at Dessau into the fundamentals of metal diffusion and technological applications. The Becker, Daeves, Steinbruck chromizing process is described.—J. G. W.

Bright Zinc Plating. R. O. Hull and J. B. Winters. (*Metal Finishing*, 1951, **49,** June, 58–61, 63). The preparation of bright zinc plating baths, their maintenance, analysis, and operation are described. Recommendations are made for plating cast iron, for bright dipping of zinc deposits and for removing hydrogen.—J. P.

Modern Hot-Dip Galvanizing. R. F. Ledford. (*Products Finishing*, 1951, **15,** Oct., 26–32). Precautions to be taken during the preparation of steel to be galvanized in order to minimize dross formation are discussed.—J. P.

Fully Automatic Galvanizing Plants. A. Smart. (*Metalloberfläche*, 1950, **2,** July, B103–B105). Design, performance, and economic aspects of fully automatic galvanizing plants for mass-production purposes are discussed.—P. F.

Preheating Tinplate Rolls : Improvement in Heater Design. (*Iron Coal Trades Rev.*, 1951, **163,** Dec. 21, 1363–1364 ; *Metallurgia*, 1951, **44,** Dec., 284–285). This article describes a trial of 'Hypact' burners, manufactured by Aeromatic Co. Ltd., for preheating tinplate rolls. The results show that a temperature rise of 250° C. will be produced in about 9½ hr., using 530 cu. ft./hr. of gas (C.V. 350 B.Th.U./cu. ft.). The design of the burner is briefly described.—G. F.

Tinning Metals by Ion Exchange Reactions and by Diffusion. (*Tekn. Ukeblad*, 1951, **98,** Aug. 30, 615–617). [In Norwegian]. The principle features of tinplating at 350–450° C. in molten tin salts are given. Iron and copper alloys are suitable for this treatment, the main advantages of which are high corrosion resistance, rapidity, and thin uniform plating.—B. S. E.

New Belgian Tinplating Line. (*Tin*, 1951, Dec., 5). A brief description is given of the first major electrolytic tinplating plant to be built on the Continent ; it is at Tilleur, Belgium. The strip passes through the line at 650 ft./min. The working roll face width is 40 in.—B. G. B.

The Development of the Tinplate Trade. H. Leighton Davies. (*J. Iron Steel Inst.*, 1952, **171,** May, 15–37). [This issue].

Differential Coated Electrolytic Tin Plate. J. J. Munns. (*Amer. Iron Steel Inst., Preprint*, 1951). The author discusses the development of the tinplate industry and the hot-dipping and electrolytic tinning methods. The practice at Weirton Steel Co. of applying 'differential' coatings, or different coating weights to each side of the sheet, is compared with the more conventional methods.—G. F.

Impregnation of Steel with Cerium. N. T. Gudstov and G. N. Dubinin. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Tekhnicheskikh Nauk*, 1951, Apr., 565–575). [In Russian]. A short critical review of data on cerium and cerium alloys is given. Experiments in which steel was impregnated with cerium are outlined and the structure and properties of the impregnated surface are described.—V. G.

Study of Chromates of Zinc and Cadmium Considered as Pigment Inhibitors of Corrosion of Various Metals and Alloys. M. Nortz and H. Rabaté. (*Peintures, Pigments, Vernis*, 1951, **27,** Dec., 765–779). The magnetic susceptibilities of several different chromates and the products of their pyrolysis were measured. The chromates were $4CrO_3.4ZnO.K_2O.3H_2O$; $4CrO_3.4ZnO.Na_2O.3H_2O$; $CrO_3.4ZnO.3H_2O$; $CrO_3.5ZnO.4H_2O$; $CrO_4Cd.CdO.2H_2O$; $4CdO.K_2O.4CrO_3.3H_2O$. The results are discussed and structures are proposed. Several zinc–potassium chromates and cadmium–potassium chromates were examined with the electron microscope.—T. E. D.

POWDER METALLURGY

Powder-Metal Parts . . . Their Physical Characteristics and Design Advantages. G. H. Logan. (*Machine Design*, 1951, **23,** Oct., 133–136). A review is given of the principles applied in producing parts by powder metallurgy, and the characteristic properties of parts, mostly non-ferrous, are pointed out.—R. A. R.

Sintered Nickel Steels. F. Benesovsky. (*Berg- Hüttenmänn. Monatsh.*, 1951, **96,** Sept., 184–187). The density, hardness, tensile strength, and elongation to fracture of sintered steels containing 2–14% of nickel and 0·0–0·7% of carbon were measured, and their metallographic structures examined. Some compacts were compressed once, others twice. If thorough diffusion is facilitated by providing high pressures and temperatures, the sintered metals have mechanical properties close to those of similar steels made by ordinary methods.—P. F.

Uniting Metals. E. Schwarz-Bergkampf. (*Berg- Hüttenmänn. Monatsh.*, 1951, **96,** May, 116–118). From the phenomenon of cold-welding of vacuum-degassed metals, which is initiated by an electron exchange in the contact areas, facilitated by the absence of adsorbed films, it is argued that even weak currents should lead to an increase in the strength of specimens made of pressed metal powders. This was true for rods of pressed iron powder.—P. F.

PROPERTIES AND TESTS

Micromechanical Testing of Metals. P. Chevenard. (*Assoc. Suisse pour l'Essai des Materiaux*, Zürich, 1947, Report No. 42). Various machines for performing mechanical tests on small samples are described, and illustrations and photographs are included. The types of result obtained are shown graphically. Scientific and practical applications are discussed.—T. E. D.

Precision in Metallurgy and the Metallurgy of Precision. P. Chevenard. (*Mém. Soc. Ing. Civils, France*, 1951, **104,** Jan.–Apr., 1–44). Progress in metallurgical theory and the accuracy of the measurement of the properties of metals is surveyed. Precision is necessary in the manufacture of high-purity alloys and special steels. The metallurgy of ferro-nickel alloys is described in detail, and many three-dimensional transformation diagrams are reproduced, showing changes in expansion and resistivity with temperature and nickel content. Some properties of alloys containing chromium and cobalt are surveyed. Invar is mentioned, and the use of ferro-nickels for electromagnetic purposes outlined.—T. E. D.

New Applications of the Micromachine Type MI/44. Sadamel Soc. An. (*Microtecnic*, 1951, **5,** Sept.–Oct., 233–240). The main characteristic features of the new micromachine designed by Prof. P. Chevenard include fracture load variations from a few grams to 100 kg., length of test pieces from 2 to 150 mm., and speed of load application 2 to 120 mm./min. Amplification of load and extension of test piece are obtained optically by precision mirrors, extension of 1 mm. of test piece may be represented by 4 mm. or 60 mm. on resultant curves. Examples of the use of the machine are given.—H. D. W.

Mechanical Tests with Micro Specimens. F. del Moral and M. Alvarez. (*Ciencia y Tecn. Soldadura*, 1951, **1,** July, 1451). [In Spanish]. A Chevenard microtesting machine is described which can effect tensile, bend, and cutting tests on very small specimens. A photographic diagram of forces and deformations is obtained. One application is the determination of the variation in mechanical properties of a hardened steel at various depths.—R. S.

Notched-Bar Tensile Tests on Heat-Treated Constructional Steels. A. Krisch. (*Arch. Eisenhüttenwesen*, 1951, **22,** Nov.–Dec., 395–400). Notched-bar tensile tests, using specimens with peripheral, hemispherical, and **V**-notches, have been carried out at +20° and −70° C. on 34 rods from two unalloyed and eight alloyed heat-treatable steels. While the tensile strength of the specimens with the hemispherical notches bore a constant ratio to the strength of the unnotched specimens, the **V**-notched specimens exhibited differences which may depend on the impact strength. The ratios of the

tensile strengths at −70° and +20° C. were the same for the hemispherically notched and the unnotched bars, but the ratios were appreciably lower with the **V**-notched bars and showed that lowering the temperature makes the test more discriminating.—J. P.

Relation of Notch Strain to Deflection in the Notch-Bend Test. E. M. Emery and A. E. Flanigan. (*Welding J.*, 1951, **30,** Dec., 607s–612s). A method has been developed for measuring the strains at the base of the notch in longitudinal notch-bend specimens used to evaluate weld ductility. For ¾-in. steel plate (0·17% C, 0·38% Mn, 0·04% Si, 0·031% S, 0·013% P), the strain/deflection relation was approximately linear over the range of strain preceding and immediately following the fracture of the weld. The strain/deflection ratio was dependent upon the metallurgical condition of the weld as well as the shape of the specimen.—U. E.

Notch Resistance of Carbon Steel Ship Plate. S. Epstein. (*Amer. Iron Steel Inst. Regional Meeting*, 1951). The author reports the results of notch resistance tests carried out on commercial ship-plate steels made to the specifications of the American Bureau of Shipping, and compares them with results obtained by the Bureau of Standards on steels from welded ships which failed by brittle fracture. Such tests are felt to be unsuitable for routine testing. The proper use of steel made to the recent specifications will greatly reduce the danger of ship failure due to brittle fracture.—G. F.

Impact Tests and the Schnadt Method. G. Broge-Andersen. (*Tidsskr. Kjemi, Bergvesen Met.*, 1951, **11,** May, 68–71). [In Norwegian]. The Schnadt theory is said to explain brittle fracture in steel. The impact test devised by Schnadt does not differ essentially from the Charpy method. The adoption of either method as a standard is urged.—B. S. E.

The Effect of Microstructure on Notch Toughness—Part I. J. H. Gross and R. D. Stout. (*Welding J.*, 1951, **30,** Oct. 481s–485s). The effect of microstructural changes on the notch toughness of steel was investigated. With a fine-grained eutectoid plain carbon steel the best notch toughness occurs at the coarsest pearlite spacing, and is lowered at an increasing rate with decreasing pearlite spacing. Coarse-grained pearlite of any given spacing exhibited lower notch toughness than corresponding fine-grained pearlite.—U. E.

Stress Analysis by Brittle Films. (*Peintures. Pigments, Vernis*, 1951, **27,** Dec., 748–757). This method is used for investigating all types of stress in a wide variety of samples. The principles, details of technique, and examples of its applications are described. It is a very rapid method to use. (31 references).—T. E. D.

The Frozen-Stress Technique of Stress Analysis. (*Mech. World*, 1951, **130,** Dec. 21, 576–578). An explanation is given of the frozen-stress technique in photoelastic stress analysis. Three-dimensional analysis is possible by its use. A general description is given of the method and its present limitations are discussed.—D. H.

General Theory of Small Elastic Deformations Superposed on Finite Elastic Deformations. A. E. Green, R. S. Rivlin, and R. T. Shield. (*Proc. Roy. Soc.*, Series A, 1952, **211,** Feb. 7, 128–154). Using tensor notations, a general theory is developed for small elastic deformations, of either a compressible or incompressible isotropic elastic body, superposed on a known finite deformation, without assuming special forms for the strain/energy function.—R. A. R.

Development Possibilities in the Modern Science of Strength of Materials. H. Neuber. (*Technik*, 1951, **6,** Nov., 487–491). The author reviews the development of elasticity theory in order to show that conventional design calculations are based on the assumption of simple shapes and idealized materials obeying Hooke's law. He then reviews more recent investigations of stress raisers and finally discusses researches into the theory of the strength of materials having a non-linear relation between stress and strain. (28 references).—J. G. W.

The Mechanism of Fracture of Pearlite. V. Zednik and Z. Kadeřávek. (*Hutnické Listy*, 1951, **6,** 5, 211–219). [In Czech]. Tests were made to determine the cause of brittleness of carbon steels with a lamellar pearlitic structure. They were carried out by examining notched specimens fractured by impact at temperatures of −195°, −78°, +20°, and +150° C. In the first stage of the fracture individual cracks occurred at the ferrite-cementite boundaries. The stress concentrations at the root of these cracks promote further disruption. The cohesion between the ferrite and cementite lamellae governs he initiation of crack formation.—E. G.

The Problem of Fatigue Strength with Different Sizes of Test Piece. M. Hempel. (*Arch. Eisenhüttenwesen*, 1951, **22,** Nov., Dec., 425–436). With increasing size of specimen, the alternating bend strength of bars approaches a lower limit which should correspond to the alternating tensile-compression strength. This implies that the alternating bend and tensile-compression strengths of small specimens (7–10 mm. in dia.) must differ. To confirm this, recent results have been applied. The mean ratio of the two fatigue limits lies in the range 0·93–1·13; a theoretical treatment suggests a value of 1·70. The influence of size on the tensile-compression strength was also examined on bars of different cross-sections (*i.e.*, drilled flat bars). In the range studied, a five-fold increase in size made no appreciable difference. Tests were carried out to determine the influence of specimen preparation, internal stress, and testing conditions on the alternating bend strength of small specimens. Mechanical polishing produces internal compressive stresses in normal specimens of 40–60 kg./sq. mm. which extend 0·02–0·05 mm. below the surface. Annealing or electrolytic polishing reduces or removes these stresses. Using shot-peened specimens, it was shown how the internal stresses vary with the value of the alternating load and its time of application, and how annealing or ageing affects the fatigue strength of such specimens. Tests on specimens electrolytically polished after drilling or notching showed that these reductions of cross-section reduced the fatigue strength. Variation of temperature from specimen to specimen or during the testing of one specimen has a marked influence on fatigue strength.—J. P.

Equipment Developed to Facilitate Fatigue Testing. (*Machinery*, 1951, **79,** Nov. 15, 851–853). Equipment developed recently by the U.S. Bureau of Standards to accelerate metal fatigue tests, including devices for stopping a testing machine when a small crack forms in a specimen, an apparatus for the uniform polishing of fatigue test specimens, and a machine for fatigue testing thin sheet specimens in bending is described.—E. C. S.

Operational Stresses in Automotive Parts. R. Schilling. (*SAE Quarterly Trans.*, 1951, **5,** Apr., 292–300). The article is concerned only with chassis members. Types of failure are described—static and fatigue—and the significance of mechanical test results is discussed. The assessment of actual operational stresses in several suspension members is also described.—P. M. C.

Hardenability of Steel and Its Testing. L. Jeníček, J. Koutecký, and F. Labonek. (*Hutnické Listy*, 1951, **6,** Jan., 5–14; Feb., 70–75; Mar., 119–128; May, 220–228; June, 270–286). [In Czech]. In Part I the authors define terms and review 15 hardenability tests now in use. In Part II a mathematical analysis of the temperature distribution in a quenched body is made. The cooling of quenched cones and wedges is examined in greater detail, and the results obtained are given. The authors apply the crystallization theory of G. Sachs to show that, with certain valid assumptions, the diagrams of the isothermal breakdown of austenite can be used as a criterion in hardenability tests. In Part III they discuss the results of Jominy tests on bars, wedges, hollow cones, and cylinders made of four low-alloy steels. The purpose of the tests was to confirm the findings derived theoretically in the previous parts. On the bases of theory, calculated cooling curves, and the interrelation between the hardness curves applicable to parts of various shapes, the authors constructed diagrams and nomograms for wedges, cones, cylinders, plates, and Jominy test bars.—E. G.

Microhardness and Its Metallurgical Applications. H. Bückle. (*Rev. Mét.* 1951, **48,** Dec., 957–965). Apparatus used, main sources of error, and the laws of microhardness are described.—A. G.

The Influence of Load and Cold Work on Microhardness. F. Vitovec. (*Berg- Hüttenmann. Monatsh.*, 1951, **96,** June, 133–136). The microhardness of metals generally decreases with increasing load on the indenter, *i.e.*, with indentation diameter. This is only in apparent contradiction with Kick's similarity law according to which the work of deformation should be proportional to the third power of the length of the indentation diagonal, because the volume participating in the deformation is not a linear measure of the volume displaced by the indenter. It is necessary to distinguish an almost completely work-hardened zone, proportional to the volume of the material displaced by the indenter, and a transition zone the thickness of which is almost independent of the indenta-

tion depth and the degree of deformation. The increase in hardness due to cold work is less with small than with large indentation depths.—P. F.

NBS Micro Hot-Hardness Tester. (*Products Finishing*, 1951, **15**, Oct., 60–64). The apparatus developed by A. Brenner at the National Bureau of Standards is described. It consists essentially of a Vickers diamond indenter mounted on a vertical shaft of fused silica, a mechanical device for raising and lowering the indenter, an electric furnace for heating the specimens, and a micrometer device for orientating the specimens.—J. P.

Hardenability and Heat-Treatment Capacity of High Quality Constructional Steels. F. Šicha. (*Hutnické Listy*, 1951, **6**, 2, 58–69). [In Czech]. The author, using nearly 600 Jominy test specimens, investigated the influence of deoxidation practice and of composition on the results of heat-treating basic open-hearth and electric-furnace steels. With suitable deoxidation, austenitic grain sizes of 6 to 10 (A.S.T.M. scale) can be obtained with Czech heat-treated steels. The influence of carbon, manganese, silicon, chromium, nickel, molybdenum, and vanadium was studied ; in the case of carbon, vanadium, and chromium, the author's results differed from those of Grossmann. Graphs are presented for converting the 'ideal' into the 'real' diameter for hardening in any quenching medium the cooling intensity of which is known.—E. G.

Effect of Cooling Rate on the Aging of Structural Steels. C. R. Felmley, C. E. Hartbower, and W. S. Pellini. (*Welding J.*, 1951, **30**, Sept., 451s–458s). The quench and strain-ageing characteristics of structural steels are dependent on the rate of cooling from 1200° F. The steels investigated included rimmed, silicon-killed, aluminium-killed, and vanadium–titanium-killed types. Rapid cooling by quenching from 1200° F. enhances ageing tendencies regardless of steel deoxidation practice. The fully killed types develop strong ageing characteristics which are otherwise absent in slow-cooled material.—U. E.

Characterizing the Brittle Tendency of Steel in Notched-Bar Tensile and Notched-Bar Impact-Tensile Tests. W. Kuntze. (*Arch. Eisenhüttenwesen*, 1951, **22**, Nov.–Dec., 387–392). The brittle tendency of a material can be attributed to three causes : (1) The natural brittleness which results from a structure visible in a microsection ; (2) the latent brittleness, which results from deposits in such small amount that they exert their mechanical effect without being microscopically detectable ; and (3) a shape brittleness which is determined not only by the form of an object but by some characteristic of the material. Concept (2) brings together a series of designations, such as impact brittleness, and age- and cold-embrittlement, as well as a wide range of transition stages in polymorphic transformations. These three causes can be assessed by measuring the reduction in area on rupture in the tensile, notched-bar tensile, and notched-bar impact tensile tests.

Temper Brittleness. J. Lomas. (*Machinery*, 1951, **79**, Nov. 22, 904–906). A table of Greaves, Fell, and Hadfield is reproduced showing the effect of different treatments on a steel containing 0·26% C, 0·07% Si, 0·66% Mn, 0·02% S, 0·026% P, 0·84% Cr, and 3·53% Ni. The effect of alloying elements and blue brittleness is discussed.—E. C. S.

Temper Embrittlement in Plain Carbon Steels. J. F. Libsch, A. E. Powers, and G. Bhat. (*Amer. Soc. Met. Preprint* 8w, 1952). It is found experimentally that plain carbon steels are highly susceptible to temper embrittlement above 455° C., and that they avoid it only if very short tempering cycles are used.—E. T. L.

Overcoming Rheotropic Brittleness: Precompression *versus* Pretension. E. J. Ripling and W. M. Baldwin, jun. (*Amer. Soc. Met. Preprint* 11w, 1952). The authors consider brittleness at low temperatures, high strain rates, and under severe notch conditions. They show that ductility in tension is improved by compressive prestrains in the same direction.

The Embrittlement of Pure Iron in Wet and Dry Hydrogen. J. K. Stanley. (*Amer. Soc. Met. Preprint* 15w, 1952). Embrittlement of pure iron in a simple bend test was found in dry hydrogen after about 10 hr. in the range 700–1150° C. In wet hydrogen, embrittlement occurred in about 1 hr. It is suggested that the formation in the metal of molecular hydrogen creates an internal pressure, and hence weakness.

Embrittlement of Tempered Martensite Better Defined. P. Payson. (*Iron Age*, 1951, **168**, Sept. 27, 86–89). The author attempts to define the types of embrittlement that can occur in tempered steels. He defines ferrite brittleness as that which occurs in annealed or normalized low-carbon steels when strained at 500–600° F. and then tested at room temperature. Soft tempered martensite brittleness occurs in most medium-carbon medium-alloy steels when the hardened steel is tempered at about 1100° F. and then cooled slowly through about 850° F., or when the hardened steel is tempered for lengthy periods at about 850–1100° F. Hard tempered martensite brittleness is caused when hardened medium-alloy steel is tempered at about 500–600° F. Notch impact tests with aluminium and titanium additions confirmed German investigations that the impact values are lowered with low-temperature tempering treatments but did not show any beneficial effects on steel tempered at 550–600° F.—A. M. F.

The Prevention of Embrittlement Cracking. A. A. Berk. (*Trans. Amer. Soc. Mech. Eng.*, 1951, **73**, Oct., 859–864). Data are presented to show that nitrate, quebracho tannin, and zero-caustic (elimination of free NaOH) treatments have been applied successfully in stationary boiler plants to prevent cracking in embrittlement-detector specimens.

Abrasion and Polishing, Friction and Wear. P. Dinichert. (*Microtecnic*, 1951, **5**, Sept.–Oct., 225–232). The contact between two solid bodies, free from any lubricating matter, is considered at the point where the highest peaks of one surface meet corresponding peaks on the opposite surface. Attempts are made to verify the disproportion between the effective and apparent contact areas by examination of the surfaces before and after contact with the election microscope, or measurement of electrical resistance. The theory of frictional force is described as that required to draw the projections of irregularities through obstacles in the way and also to tear the material in which some of the bridges of contact are anchored. The microscopical aspect of friction and wear is fully dealt with and tests show that contact between identical metals is more harmful to surfaces than between unlike metals. Details are given of methods of reducing friction and wear without lubrication.—H. D. W.

Wear from the Manufacturer's Viewpoint. G. A. P. Hunt. (Australian Inst. Met. : *Australasian Eng.*, 1951, Nov. 7, 62–69). The author describes a method of wear measurement, involving the rubbing under pressure of a specimen against a rotating drum. Cast-iron specimens and drums were used to give information applicable to piston-ring wear. Desirable cast-iron structures are described, and the effect of oxide films, hardness, and pressure is discussed.—P. M. C.

The Wear of Metals. (*Railway Steel Topics*, 1951, **1**, 1, 20–24). The mechanical wear of metals appears to be a combination of three separate phenomena, extrusion, abrasion, and fatigue. The effect of structure of the metals, intermetallic films, and the type and severity of the loading on wear is discussed. The Humphrey abrasion testing machine, wherein a 'roller' specimen and a 'dish' specimen can be tested at any controlled humidity, is described. Results showing the effect of humidity on the abrasion resistance of an experimental acid Bessemer medium-manganese rail steel and a standard oil-hardened and tempered tyre steel are given.—H. F.

Testing the Wear Resistance of Surfaces. H. Meincke. (*Metalloberfläche*, 1950, **4**, Oct., A145–A151). Wear-testing machines are discussed, and the model produced by Hochfrequenz, Feinmechanischer Gerätebau, Bad Godesberg, which was used by the author, is described. The small plate specimen is pressed by a loaded beam against a motor-driven steel disc. Results on the wear of metallic and non-metallic surfaces showed that hardness is not a true measure of wear resistance. No wear-testing standards are in use, but a suggested basis is tests in which the peripheral wheel velocity of the tester is 1·45 m./sec., the stress range 0·5–5 kg./sq. cm., and a path of 2000–10,000 m.—P. F.

Steel Processing Forum—A Challenge to Metallurgists. P. J. Wilson. (*Steel Processing*, 1951, **37**, Nov., 572–573). The author suggests that surface hardness alone is not a true indication of wear resistance. The importance of well-dispersed, hard, and correctly graded carbides throughout the depth of a case is stressed.—P. M. C.

Friction. F. P. Bowden. (*Proc. Roy. Inst.*, 1950, **34**, Part IV, 157, 634–646). The early work on friction by Leonardo da Vinci, Amontons, Coulomb, and Sir William Hardy is summarized. Recent experimental work has shown that

the area of contact between two surfaces is very small and is almost independent of the size of the surfaces but is directly proportional to the load. The surfaces were magnified by using an ordinary microscope in an oblique section, using an electron microscope, or by the effect of interference of light. The friction between two bodies is due to pressure welding at random points, which is very much reduced by even a very thin layer of lubricant. For sliding dry metals local hot-spots of up to 1000° C. occur. A plastic called Fluon, which by reason of its molecule structure has a low coefficient of friction, has been developed. When bonded with copper it reduces the coefficient of friction of copper from about 1·0 to 0·5, and is a useful bearing or anti-friction material which can be used without any lubricant and will function at quite high temperatures.—H. F.

Koepe Wheel Treads: Static Friction Tests of Various Materials and Ropes. (*Iron Coal Trades Rev.*, 1951, **163,** Dec. 14, 1289–1293). This report gives the results of tests carried out by Metropolitan-Vickers Electrical Co., Ltd., to determine, under varying surface conditions, the static coefficient of friction between three different types of steel rope, pressed in contact with a number of different wheel-tread materials submitted as being suitable for Koepe winder installations.—G. F.

METALLOGRAPHY

Electronic Microscopy. M. P. Chanson. (*Mém. Artillerie Fran.*, 1951, **25,** 1, 175–220). In chapter I, after a brief historical introduction, the general properties and nature of electrons are described with particular reference to their behaviour in magnetic and electrostatic fields. The principles of the magnetic and the electrostatic lenses are discussed in chapter II, and descriptions of actual pieces of apparatus are given. Chapter III deals with the problems arising from spherical aberration caused by electronic lenses. The final chapter briefly outlines the construction of the electron microscope, and goes on to describe its use in the observation of microstructures. Finally, the proton microscope is considered, and an experimental apparatus is described. The subject is treated mathematically throughout. (22 references).

Study of Recrystallization Phenomena by Electron Emission Microscopy. G. W. Rathenau. (*Rev. Mét.*, 1951, **48,** Dec., 923–928). Seventy cold-rolled nickel–iron face-centred-cubic alloys were studied and found to recrystallize with a cubic texture having (001) parallel to the rolling plane and [100] parallel to the rolling direction. Annealing at some higher temperature causes growth of a few large secondary crystals with specific orientations.—A. G.

The Technique of Absorption Microradiography and Some Examples of Its Application to Metallographic Investigations. Z. Bojarski. (*Prace Badawcze Glownego Inst. Met.*, 1951, **3,** No. 5, 417–427). [In Polish]. The theoretical basis of radiography and the possibilities of this method are discussed. The author differentiates between microradiography by: (1) Polar projection; (2) reflection; and (3) absorption. His technique of absorption microradiography and some examples of its application are described.—V. G.

Grain Boundaries and Creep. S. G. Glover. (*J. B'ham Met. Soc.*, 1951, **31,** June, 61–74). This author reviews the theories of the grain boundary, discusses the methods and difficulties of experimental investigation, and indicates the concept of the boundary structures which has emerged. The influence of the grain boundary on metallic creep is considered.—J. B. B.

Metallography of Alloys of Titanium with Oxygen, Carbon and Nitrogen. T. Redden and Mary J. Field. (*Steel*, 1951, **129,** Nov. 19, 88–90). The microstructure and mechanical properties of unalloyed titanium and of 0·25 wt.-% alloys of titanium with oxygen, nitrogen, and carbon under various conditions of heat-treatment are presented. The oxygen and nitrogen show the complete solubility of 0·25% of these elements in both the alpha and beta phases. The polishing and etching techniques are described.—A. M. F.

Grain Growth in High Purity Iron. G. Wiener. (*Amer. Soc. Met. Preprint* 17w, 1952). The grain growth of 99·98% iron in the range 600–875° C. has been studied, after deformations of 20 to 85%. The grain diameter increases as a simple power function of time; the power of this function increases with deformation.—E. T. L.

Heterogeneous Nucleation of Graphite in Hypo-eutectoid Steels. W. E. Dennis. (*J. Iron Steel Inst.*, 1952, **171,** May, 59–63). [This issue].

The Crystallographic Mechanism of the Martensite Reaction in Iron–Carbon Alloys. J. S. Bowles. (*Acta Crystallographica*, 1951, **4,** Mar., 162–171). It is suggested that in the transformation, each atom moves first in the austenite twinning direction and then in the martensite twinning direction. The proposed mechanism is consistent with all the geometrical features of the reaction, and good agreement is found between predicted and observed angles through which polished surfaces are tilted by the production of martensite plates.—T. E. D.

X-Ray Absorption in Crystals Set at the Bragg Angle. H. N. Campbell. (*Acta Crystallographica*, 1951, **4,** Mar., 180–181). A crystal set at the Bragg angle should show a higher apparent absorption coefficient than when off the Bragg angle. Some preliminary experiments with calcite fail to confirm the existence of this effect.—T. E. D.

An X-Ray Method of Studying Phase Changes at High Temperatures. H. T. Heal and H. Mykura. (*Rev. Mét.*, 1951, **48,** Dec., 966–969). A Geiger-Müller counter is employed to measure the intensity of one diffraction line resulting from a given phase, thus revealing the amount present. A disadvantage is the need for high X-ray intensity to ensure reasonable accuracy.—A. G.

Occurrence of Sigma Phase in High Chromium–Nickel Steel and the Effect of Carbon Content. R. E. Lismer, L. Pryce, and K. W. Andrews. (*J. Iron Steel Inst.*, 1952, **171,** May, 49–58). [This issue].

Submicroscopic Structure of Iron–Nickel–Aluminium–Copper Alloys. N. N. Buinov and P. M. Lerinman. (*Doklady Akademii Nauk S.S.S.R.*, 1951, **79,** 1, 69–72). [In Russian]. The electron microscopic examination of the submicroscopic structure of ferro-alloys containing 25% Ni, 14% Al, and 0·15% Cu was made in order to compare the structures of this alloy for different values of coercive force obtained by different thermal treatments.—V. G.

The Homogenization of Dendritic Segregations of Phosphorus and Arsenic in Alloy Steels. A. Kohn. (*Compt. Rend.*, 1951, **233,** Dec. 19, 1617–1619). Results previously obtained for carbon steels by an autoradiographic method are confirmed for alloy steels. Arsenic segregation is the more difficult to homogenize. Other alloying elements in the amounts encountered in constructional alloy steels do not seem to affect the speed of this homogenization.—A. G.

Volume Change at the Ar_3 Transformation. A. H. Smith and F. C. Thompson. (*J. Iron Steel Inst.*, 1952, **171,** May, 38–40). [This issue].

The Process and Result of Austenite Transformation at Constant Temperature. (*U.S. Steel Co. Res. Lab. Inf. Circular No.* 1, 1951). This is a simple explanation of the construction and interpretation of a typical isothermal transformation diagram.—E. T. L.

Magnetic Study of Martensite Transformations by Working, or Thermally, in Steels Containing 18% Chromium and 4 to 12% Nickel. P. Bastien and J. Dedieu. (*Compt. Rend.*, 1952, **234,** Jan. 14, 334–336). The extent of transformation is determined from the flattening of the curve of total magnetization owing to the diluting effect of the paramagnetic γ-phase. Whereas working may cause a nearly complete transformation, quenching (even to near absolute zero) only causes 15% transformation in 18/8 low-carbon steels.—A. G.

Microscopical Studies on the Iron–Nickel–Aluminium System. A. J. Bradley. (*J. Iron Steel Inst.*, 1952, **171,** May, 41–47). [This issue].

Alpha–Gamma Transformation in the Iron–Chromium–Manganese System. A. T. Grigorev, D. L. Kudryavtsev, and N. M. Gruzdeva. (*Zhurnal Prikladnoi Khimii*, 1950, **23,** 566–574). The α–γ transformation in the Fe–Cr–Mn system was investigated by hardness and dilatometric measurements and metallographic analysis.—V. G.

Relationship between Crystal Lattice Parameter of Austenite and Start of Martensite Transformation in Iron–Carbon Alloys. V. I. Arkharov. (*Doklady Akademii Nauk S.S.S.R.*, 1950, **70,** 833–836). [In Russian]. An analysis of the crystallogeometric relations involved in the austenite–martensite transformation is given.—V. G.

Concerning the Intermediate Austenite Transformation. P. I. Entin. (*Doklady Akademii Nauk S.S.S.R.*, 1951, **79,** 6, 973–976). [In Russian]. The alloying of a steel with molybdenum, chromium, or tungsten causes sharp changes in the shape of the isothermal decomposition diagram for austenite. These are: (1) Great stability in the region of

450–600° C.; and (2) two maxima of velocity of austenite transformation above and below this temperature range. The author surveys the literature and discusses the causes and mechanism of austenite transformation in this intermediate temperature range.—V. G.

Isothermal Transformation Characteristics on Direct Cooling of Alloyed White Iron. F. B. Rote, G. A. Conger, and K. A. DeLonge. (*Trans. Amer. Found. Soc.*, 1951, **59**, 509–522). This paper presents the results obtained in an investigation of the isothermal transformation characteristics of a white alloy cast iron containing nominally 3·4% T.C, 1·15% Si, 0·35% Mn, 4·5% Ni, 1·85% Cr, and 0·12% Mo. A complete **S**-curve was determined from data obtained by hardness tests and microscopical examination of wedge-shaped castings, directly air-cooled from the mould to subeutectoid temperatures for isothermal transformation.—P. C. P.

CORROSION

A Note on Filiform Corrosion. F. Hargreaves. (*J. Iron Steel Inst.*, 1952, **171**, May, 47–48). [This issue].

Protection Against Corrosion, and Low Alloy Steels. D. Bermane. (*Ossature Métallique*, 1952, **17**, Jan., 42–48). The reports on corrosion-resistant low-alloy steels and protective coatings, presented by Belgian, American, British, and French research associations are surveyed. The corrosion resistance of steels is found to increase in the following order which shows the amounts of alloying elements: (1) Mild steel; (2) Cu 0·12%, Ni 0·03%; (3) Cu 0·29%; (4) Cu 0·5%, Ni 0·48%; (5) Cr 0·41%; (6) Ni 2·07%; (7) Ni 1·58%, Cu 0·86%, Si 0·2%; and (8) Ni 5·03%, Si 0·3%. The influence of brushing and sand-blasting the surface is discussed.

Corrosion of Reinforcing Bars in Concrete, Particularly in Concrete Containing Slag, and Methods of Prevention. R. M. Berthier. (*Silicates Indust.*, 1951, **16**, Dec., 329–333). The electrochemical activity of iron and steel in concrete is studied by measuring the potential between the concrete and the metal, by means of a valve voltmeter and referred to a calomel standard cell. The domain of passivity lies between − 0·1 and − 0·5 V. below the zero level of the mercury calomel standard. This does not correspond to any given reaction and is therefore termed the 'pseudo-potential of passivity.' Outside this zone the metal is attacked. Stable protection is offered by the concrete if the potential is homogeneous in the zone of passivity, and is determined solely by the oxidation-reduction equilibrium. Corrosion risks depend practically on the quality of the concrete, the ionic conditions in the liquid content, and the manner of change of the latter.—P. F.

The Protection of Steel Bolts Used in Aluminium Structures. (*Tin and its Uses*, 1951, Dec., 3). Six different coatings were investigated. Tin–zinc coatings were the most successful.

Electrochemical Analyses of Anticorrosive Action of Emulsified Oils. A. Ferri. (*Chim. e Indust.*, 1951, **33**, Aug., 477–479). [In Italian]. The author examines by electrochemical methods the nature and mechanism of the anticorrosive action which emulsioned oils have on metals during machining. Oils are inhibitors which come into action only in the anodic process of corrosion and are therefore dangerous as they may lead to local corrosion. He examines the possibility of combining the anodic action of oils with the cathodic action of other inhibitors. This might be done with bichromate of potassium which with oil forms an 'ideal' inhibitor.

On the Mechanism and Kinetics of the Scaling of Iron. M. H. Davies, M. T. Simnad, and C. E. Birchenall. (*Trans. Amer. Inst. Min. Met. Eng.*, 1951, 889–896; *J. Met.*, 1951, **3**, Oct.). Using radioactive silver as an inert marker, the authors have determined the rates of oxidation of iron in pure oxygen over a wide temperature range; these generally agreed with those previously reported. Tentative explanations of several systematic differences are noted. In addition to multilayer scaling rates, the rates of growth of hematite on magnetite, and hematite and magnetite on wüstite, have also been determined; these rates follow a parabolic rather than a linear law, and it is concluded that the growth of each layer is a diffusion-controlled process. The experimental methods and techniques employed are described.—G. F.

The Oxidation of Heat-Resistant Alloys in the Presence of Foreign Oxides. J. L. Meijering and G. W. Rathenau. (*Philips Tech. Rev.*, 1951, **12**, Feb., 213–220). To account for the occasional accelerated oxidation of heat-resistant materials when brought into contact with foreign oxides, a series of alloys and metals has been investigated for the case where these are brought into contact, in air, with solid molybdenum oxide. The degree of oxidation was determined as a function of temperature, and these curves showed discontinuities where the oxidation was suddenly accelerated. The discontinuities lay at the eutectic temperatures of the component oxides. The accelerated oxidation is due to formation of liquid in the protective oxide skin of the alloy. Other mechanisms of accelerated corrosion were sometimes encountered. The absorption of molybdenum ions in the crystal lattice of the oxide skin, and the accompanying greater ion movement in the skin led to oxidation at temperatures well below that of the eutectic.—J. B. B.

The Influence of Carbon Smokes on the Corrosion of Metal Surfaces Exposed to Flue Gases Containing Sulphur Trioxide. R. W. Kear. (*J. Appl. Chem.*, 1951, **1**, Sept., 393–399). As the smoke concentration is increased from zero there is an initial increase in corrosion, but eventually the dew point of the gases and their corrosive properties are substantially reduced. A peak rate in corrosion obtains at 20 to 45° C. below the dew point of the gas. Carbon reduces the sulphur trioxide content of flue gases by a process of physical adsorption.—E. C. S.

Prevention of Slagging and Corrosion by Protective Coatings on Boiler Heating Surfaces Exposed to Flue Gas. H. Böhme. (*BWK*, 1951, **3**, June, 189–192). Conditions are set out which protective coatings on boiler heating surfaces must satisfy in order to be effective and practicable. Sprayed coatings of lime, graphite, and metals are examined and details given of their performance under test conditions. Graphite gave best results, deposits on tubes being light and easily removed. Lime gave heavy slag coatings firmly bonded to the tubes. Metal coatings were unsuccessful because they required chemically clean surfaces.—E. C.

On Erosion and Corrosion Damage Caused by the Use of Heavy Fuel Oils in Engines, Boilers, and Gas Turbines. B. Engel. (*Erdöl u. Kohle*, 1950, **3**, 7, 321–327). Components of heavy fuel oil which can cause corrosion and erosion and methods of removing them are discussed, and the author's experiments on the elimination of harmful components are described.—V. G.

ANALYSIS

Spectral Analysis in Steelworks. M. R. Castro. (*Mém. Soc. Ing. Civils, France*, 1951, **104**, Jan.–Apr., 62–85). The principles of spectral analysis are outlined, and details of equipment are given. Methods of preparation of samples for analysis are described, and the use of spectral analysis for non-destructive testing is emphasized. Limits of sensitivity in the detection of various trace elements in steel are given, and oxides which can be determined in slags are mentioned.

The Developments of a New Direct-Analysis Apparatus in Spectrochemistry. A. Hans. (*Rev. Univ. Min.*, 1951, Series 9, **7**, Dec., 448–457). Electron multiplier tubes are used instead of the usual photoelectric cells; one for each element to be analysed. Details of the new circuit are shown. First results have been very successful. The average quadratic error for the analysis of nickel in steel is less than 0·7%. The excellent stability of the new instrument is stressed.—B. G. B.

Study of the Spectroscopic Analysis of High-Alloy Steels. J. Eeckhout, J. Cruse, and J. Gillis. (*Rev. Univ. Min.*, 1951, Series 9, **7**, Dec., 440–447). A short review of the development of spectroscopic methods for the analysis of elements present in small concentrations, and of the principle constituent, is given. Spectroscopic determination of chromium, manganese, nickel, and silicon, occurring in high-alloy steels, has been studied systematically. The precise experimental conditions which give the optimum accuracy for their determination are reported.—B. G. B.

Spectrochemical Analysis of Ferrous Slags. Preparation of Synthetic Standards by Sintering. R. Castro and R. Londe. (*Compt. Rend.*, 1951, **233**, Oct. 29, 1031–1033). Standards are made by heating the finely ground constituents in a platinum crucible at 1200° C. Samples diluted to 5–10% with nickel powder are subjected to a unidirectional intermittent arc.—A. G

A Precision Polarograph for Chemical Analysis. H. A. Dell and C. H. R. Gentry. (*Electronic Eng.*, 1952, **24**, Jan.

19–21). The theory of electrical deposition on a cathode immersed in a chemical solution is described, and typical polarographic curves of current against applied potential are given. A dropping mercury cathode ensures a continually clean surface to receive ions, but introduces instrumentation difficulties. Existing polarographs are fitted with long-period galvanometers, which lead to a limitation in accuracy. Full circuit details are given for methods of analysis where a cathode-ray tube is used as a detector.—H. D. W.

Determination of Molybdenum in Iron and Low-Alloy Steels Containing up to 0·5% Tungsten. Methods of Analysis Committee (*J. Iron Steel Inst.*, 1952, **171**, May, 75–80). [This issue].

Determination of Vanadium in Carbon and Low-Alloy Steels and Irons. Methods of Analysis Committee. (*J. Iron Steel Inst.*, 1952, **171**, May, 81–85). [This issue].

Organic Reagents in Inorganic Analysis. W. I. Stephen. (*Chem. Age*, 1952, **66**, Jan. 12, 47–52). A review is given of recent developments; the following reagents are proposed for the metal stated: Nioxime or heptoxime (gravimetric) nickel; nioxime also for palladium; cuproine (colorimetric) copper; alkannin or naphthazarin (colorimetric) beryllium; α-picoline (gravimetric) beryllium; methyl violet (colorimetric) or gossypol (spot test) antimony; rubeanic and silicotungstic acids (colorimetric) bismuth; ; chloramine T and methyl red (qualitative) bismuth; 3 : 3′dimethylnaphthidine (indicator for volumetric) cadmium; potassium xanthate (qualitative) cadmium; sodium salt of 1-amino-2-naphthol-6-sulphonic acid (colorimetric) magnesium; cystine (gravimetric separation) copper, cobalt, nickel, and zinc; quinaldic acid or ferron (gravimetric) thorium; isatin β-oxime (gravimetric) and oxalohydroxamic acid (qualitative) uranium; sodium flavianate or mandelic acid (gravimetric) zirconium; 2 : 2′dipyridyl or 1 : 10′phenanthroline (gravimetric) palladic palladium; sym-di-o-tolylurea platinum; thiobarbituric acid (gravimetric), 2 mercapto 4 : 5 dimethyl thiazole (colorimetric) rhodium; Yoe's reagent (gravimetric), toluene 2 : 3 dithiol (colorimetric) tungsten; 3 : 3′dimethyl naphthidine, zinc or vanadium; thioacetamide (gravimetric) tin, antimony, bismuth, molybdenum, copper, arsenic (III and V valent), cadmium, and lead; thioformamide (gravimetric) copper and arsenic. (36 references).—B. G. B.

Photoelectric Semi-Microdetermination of Titanium in Acid-Resisting Steel. A. I. Kokorin. (*Zavodskaya Laboratoriya*, 1950, **16**, 7, 777–780). A colorimetric method of determination of titanium in steel, based on the reduction of silicomolybdate is described.—V. G.

New Physical Instruments for Gas Analysis. B. Sturm. (*BWK*, 1951, **3**, Nov., 374–377). An outline of principles of the magnetic determination of oxygen is followed by descriptions of new German and other oxygen meters and recorders. An infra-red recording meter for low concentrations of CO is described..—E. C.

On the Quantitative Analysis of Gas Mixtures which Contain Nitrogen as well as Various Oxides of Nitrogen. G. Meyer and P. Voogel. (*Rec. Trav. Chim. Pays-Bas*, 1951, **70**, Sept.–Oct., 833–840). The method employs the decomposition of oxides of nitrogen by finely divided nickel at 800° C. The oxygen taken up by the nickel is determined by reduction with hydrogen. NO_2 must be condensed in a trap cooled with solid CO_2 and alcohol, and determined separately. The accuracy of the method is discussed and some determinations are quoted.

Recent French Contributions to Gas Analysis in Iron and Steel Products. E. Jaudon. (*Mét. Constr. Mécan.*, 1951, **83**, Nov., 840–845; 871). The article reviews known methods of determining oxygen, hydrogen, and nitrogen with a note on some French apparatus and methods.—R. S.

Determination of SO_2 and SO_3 in Flue Gases. P. F. Corbett and W. M. Crane. (*Brit. Coal Utilisation Res. Assoc., Monthly Bull.*, 1952, **16**, Jan., 1–11, Review Series 111). The literature is reviewed. (59 references).—R. A. R.

How to Obtain Accurate Carbon Analyses. W. H. White. (*Foundry*, 1951, **79**, Sept., 107). Widely different carbon determinations have been recorded when foundry iron samples have been taken without sufficient care and posted to a distant laboratory. A selected piece of the casting should be sent for analysis and not just drillings, since uncombined carbon can be easily lost. For total-carbon estimations a sample may be obtained by pouring some of the liquid iron into water, thus making chilled shot.—E. J. D. S.

Determination of Manganese in Ferro-Alloys and in Manganese Ores by Direct Oxidation with Silver Peroxide. D. Rosi and I. Mendola. (*Met. Ital.*, 1951, **43**, Oct., 443–445). The above method of analysis is studied. It aims at overcoming the difficulties due to the simultaneous presence of ammonium persulphate and silver nitrate. (20 references).—M. D. J. B.

HISTORICAL

A Half Century of Industrial Progress with Steel. M. W. Reed. (*Business, Big and Small, Built America*: United States Steel Corp., 1950, Apr., 55–68). Evolution in the American steel industry is reviewed from 1860 onwards, with particular reference to the United States Steel Corp., which was formed in 1901. There has been a trend away from many small plants to fewer and larger plants. Ingot production and ingot capacity are tabulated and shown graphically.

The History of the Iron-Producing Industry in the District of Dombrowa. (*Stahl u. Eisen*, 1951, **71**, Sept. 27, 1049–1055). The development of iron production, the raw materials supply, and the inter-company relations in the above district are discussed.—J. P.

Creators of the Steel Age—IV : Percy Carlyle Gilchrist, F.R.S. R. Edwards. (*Brit. Steelmaker*, 1951, **17**, Nov., 580–588). Although Percy Carlyle Gilchrist is not as well known as his cousin Sidney Gilchrist Thomas, he contributed in no less measure to the successful result which they finally achieved. This article evaluates Gilchrist's contribution to the basic steelmaking process, and explains why he has been overshadowed by his cousin.—G. F.

Three Centuries of Cast Iron Metallurgy. R. Doat and R. Evrard. (*Amer. Foundryman*, 1951, **20**, Aug., 58–60). About 50 iron castings from Belgium and Luxembourg made in the period 1500–1900, 11 from France made between 1584 and 1738, 18 from Germany made between 1547 and 1738, and some XVIth century British castings have been examined; the changes in C/Si ratio over these periods are discussed.

Early Refining of Pig Iron in England. H. R. Schubert. (*Newcomen Soc. Preprint*, Jan. 9, 1952). The author describes in detail the construction of an early English finery hearth, the tools, and the process. (70 references).—R. A. R.

Early Use of Cast Iron for Furnace Tops. H. R. Schubert. (*J. Iron Steel Inst.*, 1952, **170**, April, 320). Evidence is given to show that cast-iron plates were made as early as 1591 for the protection of charcoal blast-furnace mouths.

Production of Pig Iron Past and Present. O. Hájiček. (*Hutnik* (Prague), 1951, **1**, No. 3, 59). [In Czech]. An illustrated historical survey of pig-iron production from Roman to modern times is given.—P. F.

The Development of Small Bessemer Converters from their Beginnings to the Present Time. H. Wolff. (*Giesserei*, 1951, **38**, Nov. 1, 565–572). This is an historical survey of the small converters of Clapp-Griffith, Walrand-Delattre, Robert, Tropenas, and Zenzes. The possibility is also discussed of combining the duplex and triplex processes with the use of cupolas, open-hearth and electric furnaces, and small converters.—J. G. W.

Evolution of the Technique of Manufacture of Sheets and Tinplate. P. Desfossez. (*Etudes Document. Mét.*, 1951, July–Aug.–Sept., Dec., 75–93). An historical survey of the old works of Dilling from 1685 is given. The present works, rebuilt since 1945, includes three coke-oven batteries, four blast-furnaces, four Bessemer converters, five open-hearth furnaces, and fully equipped rolling mills. Mill operation and tinplate production are outlined.—T. E. D.

Forest Forges and Iron Smelting Plants in the Solmser Land. R. Herwig. (*Arch. Eisenhüttenwesen*, 1951, **22**, Nov.–Dec., 343–354). The history of ferrous metallurgy in the Lahn district is reviewed. Traces of iron smelting, which date back to Carlovingian times have been found in the Solmser Land in the Wetzlar region. The development from peasant smelting up to the flourishing state of the town of Wetzlar in the XIIIth century is traced. Direct smelting in the Lahn-Dill district declined in the XVIIth century.—J. P.

Forerunner to Our Forerunner. (*Iscor News*, 1951, **16**, Dec., 1085–1089). The forerunner of the South African Iron and Steel Corporation, Iscor's forerunner, was the Pretoria Iron Mines, Ltd., which was founded in 1917; a short account of its history is given.—T. E. D.

ECONOMICS AND STATISTICS

The British Iron and Steel Industry in 1951. (*Engineer*, 1952, **193,** Jan. 4, 15–18 ; Jan. 11, 66–68). A detailed survey is given of the activities of the British iron and steel industry in 1951. The effects of nationalization and subsequent denationalization are considered and the tonnage output for the year is discussed.—M. D. J. B.

The West German Coal and Steel Industries Since the War. (*World Today*, 1952, **8,** Mar., 111–123). This review contains many statistics of production. In the first half of 1951 steel production was 6·44 million tons. Before 1939 Germany imported scrap. In the three years from the summer of 1948 to 1951, 6 million tons were exported out of a total scrap production in Western Germany of 20 million tons.—R. A. R.

The Problem of Iron Ore Supplies to the German Iron and Steel Industry. A. Voigt. (*Bulwark*, 1951, Dec., 3–6). A survey is made of the ore supply position in 1937 compared with that in post-war years.—T. E. D.

Some Observations on the Developments of the Iron and Steel Industry in Relation to the Industrial Growth of the Country. P. Kutar. (*Indian Inst. Met. Presidential Address*, 5th Annual General Meeting). The Indian iron and steel industry and its expansion programme are discussed.—T. E. D.

Metallic Requirements and Supplies in the Western States. J. L. Ashby. (*Amer. Iron Steel Inst.*, 1951, *Preprint*).

The Iron and Steel Industry of the U.S.S.R. (*Metal Bull.*, 1952, Jan. 15, 9–18). The iron and steel industry of the U.S.S.R. can be divided into ten regions, the most important being the Dneiper, Urals, and Kuzbas. The Post-War Five Year Plan ending in Dec. 1950 is outlined, and a regional review is given, with the aid of maps, of all Soviet iron and steel plants, with details of numbers and types of furnaces, capacities, and products.—T. E. D.

MISCELLANEOUS

Application of Statistical Methods. G. F. Komlosy. (*J. B'ham Met. Soc.*, 1951, **31,** Dec., 178–192). The first part of the paper deals briefly with statistical methods and techniques which have been found helpful in solving steelworks problems, *i.e.*, study of distributions, differences between means, regression, designed experiments, sampling schemes, and quality control. Typical applications are then described.—P. M. C.

Statistical Quality Control of Metalworking Operations. L. F. Spencer. (*Steel Processing*, 1951, **37,** July, 336–339 ; Aug., 382–388, 390, 398 ; Oct., 506–508 ; Nov. 567, 568, 576). The author discusses various sampling plans and the application of control charts based on frequency distribution of measured variables (such as composition, hardness, dimensions, etc.). Average and range charts are described, and many actual tables of results and graphs are shown relating to various forging operations. The use of control charts for the inspection of attributes, and the functions and use of inspectors and quality control staffs are discussed. (16 references).—P. M. C.

The Use of Statistical Methods in the Study of Steel Plant Operating Data. W. E. Marshall. (*Amer. Iron Steel Inst.*, 1951, *Preprint*). The author describes examples of the applications of statistical methods in several fields of the steel industry. The derivation and interpretation of distribution curves and control charts are discussed, and the techniques of correlation are considered in detail.—G. F.

Planning and Control of Working Times and Cost of Extensive Construction Work and Repairs in Iron and Steel Plants. W. Schütte. (*Stahl u. Eisen*, 1951, **71,** Nov. 8, 1233–1238). A procedure evolved for this purpose at a large iron and steel works and the forms and charts needed are described.—J. P.

Present Status of Analytical Job Evaluation in the Plants of the Iron and Steel Industry. H. Euler. (*Stahl u. Eisen*, 1951, **71,** Nov. 8, 1241–1242). The present position of job evaluation, as a guide to wage rates, in the German iron and steel industry is reviewed statistically.—J. P.

Some Industrial Uses of Radio Isotopes. J. L. Putman. (*Coke Gas*, 1951, **13,** Oct., 365–369 ; Nov., 405–407). A survey is given of the properties and production of radio isotopes and methods for their detection. The uses of these isotopes for detecting underground pipes, investigating the movement of coal in retorts, following fractional distillation processes, and examining the chemical form in which sulphur is transferred from coal to coke are typical of their many industrial applications. Autoradiography and gamma-ray radiography are described as useful industrial methods, and thickness measurements are also outlined. Health hazards are negligible in most activities, provided reasonable and sensible precautions are taken.—T. E. D.

Iron and Steel Works Applications of Radio-Active Isotopes for Radiography. J. S. Blair. (*Iron Coal Trades Rev.*, 1951, **163,** Dec. 21, 1349–1354, 1356 ; Dec. 28, 1405–1410). The author discusses the metallurgical applications of radio-active isotopes for radiography, and describes the radiographic techniques which have been developed at the Corby Works of Stewarts and Lloyds Ltd. over the past two years. The different methods of radiography are compared, and the differences in the photographic material and in processing the films are considered. Particular attention is given to the safety precautions when working with radio-active materials, and the storage and transport devices used at Corby to avoid human contact with active rays are discussed.—G. F.

Radioactive Isotopes in Ferrous Metallurgy. C. M. Parker. (*Amer. Iron Steel Inst.*, 1951, *Preprint*). The author first discusses the behaviour of radio-active isotopes, and describes some applications in the field of ferrous metallurgy, particularly in the physical chemistry of steelmaking, and in certain types of gauge and measuring instruments.—G. F.

The Co-ordination of Technology and Science to Assist Progress in Ferrous Metallurgy. A. Michel. (*Mét. Constr. Mécan.*, 1951, **83,** Nov., 808–819). Improvements in methods of testing metals and the introduction of new techniques such as statistical investigations, are surveyed. The article contains notes on nine famous French scientists. The importance of good relations between research and production is stressed. A map shows the locations of French special steelworks. A number of special problems in metallurgy and their significance are briefly stated.—R. S.

Industrial Metallurgy at Birmingham University. A. R. E. Singer and V. Kondic. (*Metal Ind.*, 1951, **79,** Sept. 21, 235–239, 243 ; Sept. 28, 263–265). The general organization, facilities, and aims of the Dept. of Industrial Metallurgy, which is housed in the new Aitchison Laboratory, are described. The two main sections are metal working, and melting and casting. The equipment is described.—P. M. C.

The Metallurgical Activities of IRSID. M. A. Portevin. (*Revue Technique Luxembourgeoise*, 1951, Series 9, **7,** Oct.–Dec., 173–186). A description is given of the new laboratories of IRSID, some of which are still under construction. The research work is divided into five sections dealing with coke, minerals, the blast-furnace, manufacture of steel, and properties of steel. A short review of the type of work done in each section is made. A list of over 160 technical and theoretical investigations carried out is given together with a summary of publications.—B. G. B.

The Interception of Radiant Heat with the Aid of Wire Gauze. V. Broïda. (*Chaleur et Ind.*, 1951, **32,** Dec., 347–352). Wire gauze is used for protection against radiation from incandescent objects. A simplified mathematical treatment of the interception of radiation by metal meshes is presented, and experimentally obtained results confirm the validity of the treatment. Copper, brass, bronze, and steel meshes were examined, and of these, steel, the poorest conductor, was the most efficient interceptor. The most desirable relationship between size of space and diameter of wire is also studied.—T. E. D.

"How to Organize an Engineering Dept."—A Round Table Symposium. F. M. Darner, L. Larson, G. S. Monks, C. A. Butler, and R. W. Chaffee. (*Iron Steel Eng.*, 1951, **28,** Nov., 53–61). A symposium is reported on organizational problems in engineering departments with a view to stimulating engineering supervisors and helping them to make decisions. Organization diagrams for certain plants or departments in two American steel companies are given.—M. D. J. B.

Safety in the Clabecq Ironworks. M. Stassin. (*P.A.C.T.*, 1951, Dec. 434–436). The organization of a centralized 'Safety–Health' service is described and its method of operation is outlined.—T. E. D.

Occupational Diseases in Metal-Surface Work. K. H. Sroka. (*Metalloberfläche*, 1950, **4,** Oct., A154–A157). Dust hazards to health in metal surface work and skin troubles due to the effects of oils, grinding and polishing pastes, metal oxides, some pure metals, organic solvents, etc., are discussed.

New Work on Flow Measurement. R. Witte. (*BWK.*, 1951, **3,** Nov., 378–380). Recent investigations on the funda-

mentals of flow measurement are reviewed with special reference to the work of the Amer. Soc. Mech. Eng. Special Research Committee on Fluid Meters. (19 references).—R. A. R.

Stitch It Instead. A. G. Denne. (*Iron Age*, 1951, **168**, July 19, 97–100; July 26, 78–82). The operation of metal stitching machines and the performance of this method of fabrication are described. Any materials can be joined and examples of the types of stitch that can be used together with numerous applications are cited.—A. M. F.

Steel Plant Water Conservation. G. B. McMeans. (*Amer. Iron Steel Inst.*, 1951, *Preprint*). The location of the Fontana plant of the Kaiser Steel Corp. necessitates conservation of water used in the plant. The layout of the water system and the means by which economies are effected are described. The plant recirculates 45,000 gallons of water per ton of steel produced.—G. F.

Conversion of Filters to Zeolite Softeners. J. H. Krapf. (*Iron Steel Eng.*, 1951, **28**, Nov., 98–102). This paper describes how the very serious shortage of soda ash which occurred in the summer of 1950 was met and how the American iron and steel industry was able to maintain a high level of production despite the shortage. The author describes the method used, which reduced soda ash consumption in feedwater treatment by 85%.—M. D. J. B.

BOOK NOTICES

Benbow, W. E. "*Steels in Modern Industry.*" A comprehensive survey by 29 specialist contributors. General editor: W. E. Benbow. 8vo, pp. viii + 562. Illustrated. London, 1951: Iliffe & Sons, Ltd. (Price 42*s.*)

This is an extremely interesting book on what may be summed up as the engineering metallurgy of steel. It is written by a number of specialists, including such names as T. P. Hoar, Hugh O'Neill, D. A. Oliver, and K. J. B. Wolfe.

A short introduction of about 30 pages by the editor, in which the general metallurgy of steel is reviewed, is followed by detailed sections on the important properties of steels and the factors causing deterioration in service. Thus wear, fatigue, creep, corrosion, scaling resistance, weldability, and machinability are covered in separate sections. There are then 13 sections on specific user aspects, which, in particular, should prove interesting to the metallurgist. These aspects range through structural, aircraft, automobile and electrical engineering, gas and steam turbines, boilers and piping, and pressure vessels, to those of tools and dies, cold pressing and related operations, and of the chemical industry. Finally, there are five sections on surface treatment of steel, making in all 26 sections.

The matter is up-to-date and presented in a clear and interesting manner and is suitably illustrated. However, the type seems rather small to the reviewer and the paper is not especially pleasing.

This is the sort of book which should be possessed by all engineers and should be of extreme interest to metallurgists, especially in that it presents the user point of view so well.—A. R. Bailey

"*Gmelins Handbuch der anorganischen Chemie.*" System-Nummer 3, "*Sauerstoff.*" Lieferung 2. "*Vorkommen. Technologie.* La. 8vo, pp. iv + 217. 1952: Verlag Chemie, G.m.b.H., Weinheim/Bergstrasse. (Price DM 65.–)

An earlier issue, published in 1943, of this well-known series of handbooks having dealt with historical aspects of the knowledge of fire, combustion, and the discovery of the element oxygen, the present issue completes the story of oxygen by reviewing the literature to the end of 1949. The first section (44 pages) covers the occurrence of oxygen and ozone. This is followed by another short section on the occurrence of water (53 pages), after which comes the longest section in the book (116 pages) dealing with the literature on the production of oxygen, ozone, water, and hydrogen peroxide. The book concludes with three pages of references to the physiological effects of oxygen, ozone, water, heavy water, and hydrogen peroxide in human beings.—R. A. R.

Guy, Albert G. "*Elements of Physical Metallurgy.*" 8vo, pp. ix + 293. Illustrated. Cambridge, Mass., 1951: Addison-Wesley Press, Inc. (Price $6.50).

This book is intended, as the author states in the preface, to serve as a textbook for courses in the fundamentals of physical metallurgy for science, engineering, and metallurgy students. It could serve this purpose admirably. It should not, however, be regarded as a self-sufficient introduction to the subject, but should be read in conjunction with an appropriate course of lectures or with the guidance of a tutor. In making this reservation, the intention is not to imply that the text lacks clarity or that the treatment is too advanced for a beginner. In fact, the text is well written, clear and concise, and is enlightened by many well-chosen illustrations, about some of which there is a strip-cartoon atmosphere, which in no way detracts from their serious value. The reason why the reader will require some assistance, if he is a newcomer to the subject and is to derive full benefit from the book, is that it is really a 'digest' of present-day knowledge and views concerning many of the more important aspects of physical metallurgy. It is packed with information, sometimes perhaps a little too tightly; some of the tables, for instance, could be expanded to several pages of written matter without padding. On many matters the author simply states his own views and conclusions, and though these are in nearly all cases acceptable, the student will or should want to know on what evidence they are based. For this evidence he will have to turn to some other source of information.

The book opens with 28 crowded pages dealing with the history of metallurgy, and with extraction, casting, and forming processes; to what extent this is helpful is a matter of opinion. Then follow two chapters on the structure of metallic atoms, vapour, liquids, and crystals. The next three chapters deal with equilibrium diagrams and the structure and physical properties of alloys. The next two are concerned with elasticity and plasticity, and with mechanical properties and testing; some readers may feel that the mathematical analysis of stress/strain relations is overdone, but this type of treatment may appeal to engineering students. Corrosion, diffusion, recrystallization, grain growth, and age-hardening are surveyed in four brief chapters, and the final chapter touches on many aspects of the heat-treatment of carbon and alloy steels. There is an unusual and useful appendix, which might be described as a guide to metallurgical technical literature.

There is so much in this book that deserves high praise that even the few mildly critical comments made above may give an unfair impression, but this is difficult to avoid in a brief review.—M. S. Fisher

Thews, Edmund R. "*Metallurgische Verarbeitung von Altmetallen und Rückständen.*" Band II. "*Altrotmetalle.*" 8vo, pp. 290. Illustrated. München, 1951: Carl Hanser Verlag. (Price DM 31.50)

This admirable book deals comprehensively with every aspect of the recovery of copper and copper-alloy scrap from the sorting of the mixed scrap to its fabrication into a high-grade technically usable casting or ingot.

In the first chapter the author says that in the ruins of Berlin alone it is estimated that there are about 35,000 tons of non-ferrous metals of which the greater part is copper alloys. He then stresses the necessity of careful preliminary sorting, and points out that one is helped in the identification of the probable composition of the metal, not only by its colour but also by its form, *i.e.*, wire is usually very nearly pure copper. In the case of turnings, if these are small and appear to have been produced at high speed, it is probable that the brass contains from 1 to 2% lead, whereas if the turnings are long and elastic it is probably more or less free from lead. The author further points out that all copper alloys are not red, but may be more or less colourless.

In the second chapter the author deals with the general working conditions for the recovery of 'red' metal scrap, and considers at considerable length losses due to volatilization and oxidation, heating technique, fluxes, etc. Chapter 3 is devoted to a consideration of the remelting of copper scrap, *i.e.*, copper wire, copper sheets, and copper segments, and the production of sound castings from it.

The use of reverberatory furnaces and shaft furnaces

for the recovery of scrap metals forms the subject matter for chapter 4, whilst chapter 5 deals with the melting of copper in a cupola furnace.

Chapter 6 covers the refining of old copper and the reactions with acid and basic hearths. A section is also devoted to polishing, sampling, and casting. Chapter 7 is devoted to the production of heavy copper castings. The recovery of old brass is dealt with in chapter 8 and chapter 9 deals with the recovery of special brasses and chapter 10 with the sorting and recovery of bronzes. Chapters 11 and 12 consider at considerable length the various metallurgical problems that arise during the recovery of scrap metals. In chapter 13 the author discusses the treatment of scrap copper alloys in a converter.

Chapter 14, which deals with the separation of white-metal turnings from red-metal turnings by differential melting, is particularly interesting, although in a footnote the author states that it is not yet commercial practice. Two methods are described—sieving, and treatment in hot oil or molten salt. Vibrating and rotating sieves are used and these work at approximately 450° C. Particulars are given of mesh size, inclination of sieve, sieve speed, and furnace temperature. In the oil or molten-salt method the mixed turnings are placed in a liquid bath maintained at a temperature above that of the melting point of the white-metal turnings. The author does not specify a suitable oil but does specify a mixture consisting of boric acid and borax with a melting point between 250 and 300° C.

Chapters 15 and 16 deal with the difficult question of the desoldering of motor-car radiators and the separation of lead from lead-enclosed copper cables. Chapter 17 consists of a table giving the compositions of over 400 copper alloys. Chapters 18, 19, and 20 are concerned with crucible furnaces, electric melting furnaces, and rotating-drum furnaces, respectively. The lastcha pter is devoted to a consideration of lead poisoning and metal-fume fever.

J. FERDINAND KAYSER

THRING, M. W. "*The Science of Flames and Furnaces.*" 8vo, pp. xiv + 416. Illustrated. London, 1952: Chapman and Hall, Ltd. (Price 42*s*.)

The author in his introduction describes his somewhat unusual approach to the subject. He says that he intends to stress the gap between fundamental sciences, such as physics, chemistry, and physical chemistry and industrial furnace design and use. He recommends the 'diagnostic' approach to the ailments of existing furnaces and, finally, hopes to present the problem of furnace heating in a way that will be of interest to both the academic scientist and the engineer-in-charge of design and operation of furnaces. He has certainly gone a long way to meeting these objectives, and in so doing has produced a book that differs markedly from any other on the subject and one that should prove of great value not only to the research worker but also to the operator.

During recent years the gap between fundamental science and actual furnaces has been greatly reduced by the instrumentation, and more recently the automatic control, of furnaces, much of which arose from the diagnostic treatment recommended by the author. The Templeborough trials (*Iron and Steel Institute Special Report No.* 37), which largely originated from his suggestions, made a very substantial contribution, but a great deal still remains to be done. At present the mere fact that a particular furnace has never done well is often accepted as a reason why it should not do well in the future.

The practical furnaceman, and for that matter most research workers, will find this book rather heavy going if they attempt to read it from cover to cover. Most of them will be content to select the particular section they are interested in at the moment, and in doing so may feel frustrated by the lack of an author index. It is much easier to look up Groume Grjimailo than find in a subject index the particular entry—*e.g.*, furnaces, buoyancy—used to cover this type of work. An amplification of the subject index would also be of help.

Following an introductory chapter on the functions of a furnace, the author deals with the thermodynamics of furnace heating, with particular reference to the first and second laws. In applying the latter Thring prefers the conception of virtue, rather than its inverse of entropy. To those who have already assimilated the conception of entropy this may be annoying, but for most people the virtue defined as "the amount of that energy which could be converted into work in an ideally perfect system" will be easier to grasp.

In the third and fourth chapters Thring deals with the liberation of heat by combustion and heat transfer to the stock. In both these and the next chapter on the aerodynamics of hot systems, he gives the latest information in a way not provided by any other book. The aerodynamics section in particular will be of help to those in Britain and abroad who are beginning to think of flow pattern, rates of mixing, and pressure-loss calculations as the logical starting point for furnace design.

In the next chapter, on the science of furnace construction, he deals clearly with both refractories and furnace design, whilst in the final chapter he tackles rather ambitiously the scientific approach to the furnace problem, starting with the diagnostic treatment and the various types of probe used for such things as gas sampling and temperature measurement. He also discusses the somewhat controversial subject of the statistical approach, which, whatever the critics may say, is bound to find some place in the ultimate scheme of things.

The last section of all, entitled "Inventing a New Furnace," will be disappointing to those who hope to find a ready-made design. They will in fact find a philosophical essay. The author stresses the point made by Sir Andrew McCance in his Presidential Address to The Iron and Steel Institute, that major inventions tend to arise when both a great need and the release of new information happen to coincide. In a field where there has been nearly a hundred years' experimentation, however, a third factor may be necessary, *viz.*, inventive genius, and Thring rightly states that "no general recipe can be given for invention." It is still possible that the furnace of the future will arise quite logically from the rapidly developing background so ably summarized in this book, but a few 'originals' still seem to be required if an improvement as radical as that made, for instance, by Siemens in investing the regenerative furnace is again to be achieved.—J. H. CHESTERS

VOGEL, OTTO. "*Handbuch der Metallbeizerei.*" Band II, "*Eisenwerkstoffe.*" Zweite, erweitete Auflage. Bearbeitet von Hermine Vogel und Dr.-Ing. Alfred Keller unter Mitwirkung namhafter Fachleute. La. 8vo, pp. xvi + 538. Illustrated. Weinheim/Bergstrasse, 1951: Verlag Chemie. (Price DM. 63.–)

The fact that the first edition of this handbook was sold out within ten months was an indication of its usefulness. The second, revised, edition deserves a similar reception. It merits a place on the bookshelf as a standard source for constant reference in every works carrying out pickling. Dr. Vogel died in 1946 and this volume has been revised by his daughter in collaboration with workers who are well known for their contributions to the chemistry and metallurgy of pickling. The revision has consisted, in general, of introducing, where appropriate, matter which has been published since 1943, so that the book conforms to the plan of the first edition.

The book is severely practical, yet this does not prevent its being easily read, and theoretical considerations are introduced when these are necessary for the understanding of the function of the various pickling acids and addition agents. No important technical development appears to have been omitted.

The first chapter traces the history of etching and pickling of iron and steel from pre-Christian times to the middle of the XIXth century, when mineral acids began to be widely used instead of the organic acids derived from fermented fruits, vegetables, or cereals. If more space is devoted to Germany than to France, England, or Sweden, this is understandable, since pickling in these three countries may be considered to have started when the manufacture of tinplate was introduced from Germany.

The second chapter deals with the theoretical background of pickling and is written by Dr. P. Dickens and Dr. E. Brauns. This extremely useful survey covers the formation and nature of scale, the solution of scale and metal in acids, and the mechanism of pickling proper. Sufficient attention is given to inhibitors to indicate their value in reducing acid consumption and metal loss, but the present state of knowledge of their modes of action does not justify a more

elaborate treatment. Adequate space is devoted to the effects of hydrogen absorbed by the metal during pickling, and all relevant research work on hydrogen diffusion, pickle blisters, and hydrogen embrittlement appears to have been covered.

The third and fourth chapters will be of interest to the works engineer; they describe plant and equipment for the pickling shop. Nothing is overlooked, from the most suitable layout, construction of pickling tanks, machines, conveyor systems, acid and metal supplies, etc., to the heating of solutions, lighting and ventilation of shops, and disposal of waste liquors.

Dr. A. Keller contributes a short chapter on the acids used in pickling, the form in which they are available and their advantages and disadvantages as pickling agents. Some dozen pages are devoted to the testing of pickling and neutralizing liquors. This chapter, written by the late Dr. Westhoff and Dr. Dickens, covers analyses for iron and free acid, and, what is perhaps often forgotten, testing for the efficiency of inhibiting action.

Water economy and conservation are dealt with by Dr. K. Guthmann, and, since water is none too plentiful in Britain, this chapter will repay close scrutiny, as will also the following one on the regeneration of spent pickle liquors. Various methods are described for separating ferrous sulphate and reclaiming free acid; possible uses of the former are indicated. The treatment here is thorough and includes all published work known to the reviewer. Dr. F. Sierp has written a chapter on the effects of waste washwater on streams and rivers and on marine life; disposal by percolation through the ground and by neutralization is discussed.

Hygiene, occupational hazards, diseases, and accidents are not forgotten. The injuries which can be caused by the various acids and alkalis are described, and suitable precautionary and first-aid measures are advocated.

Chapters 13 to 23 are concerned with the practical aspects of carrying out pickling operations. It is not possible to indicate here the thoroughness with which this has been done; suffice it to say that wire, sheet, continuous strip, and bar and tube pickling are fully dealt with, and separate chapters are also devoted to the pickling of cast iron, forgings, pressings, stainless steels, and materials to be vitreous-enamelled.

An appendix of nine chapters covers matter which is not exactly pickling but which is related thereto. Here is to be found information on de-rusting, cleaning of antique discoveries and museum pieces, bright pickling, file sharpening, descaling boiler tubes, and etching for both decorative and metallographic purposes. A useful table of some 40 reagents for macro-etchants, with indications of the use for which each is suitable, is included.

The book is well bound and well printed on good paper. It is profusely illustrated, and almost without exception the photographs, sketches, and diagrams are well reproduced. The indexing is satisfactory, even though certain Scotsmen have been treated as though "Mc" were a christian name. A praiseworthy feature is the insertion after each chapter of a list of references to the subject discussed therein, additional to those quoted in the text. Because of the layout, it is possible, on any branch of the practice or science of pickling, to refer directly to an appropriate chapter without having to have read all previous chapters, even though this involves a certain amount of repetition, and the literature list ensures that no important subsequent publication is missed.—J. PEARSON

NEW PUBLICATIONS

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